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NOISE ATTENUATION IN STRAIGHT VENTILATION DUCTING

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NOISE ATTENUATION IN STRAIGHT VENTILATION LUCTING

by

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at the

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June, 1957

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May 20, 1957

Professor Leicester F. Hamilton
Secretary of the Faculty
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Cambridge, Massachusetts

Dear Professor Hamilton:

In accordance with the requirements for the degrees of Naval Engineer and Master of Science in Naval Architecture and Marine Engineering, we submit herewith a thesis entitled: "Noise Attenuation in Straight Ventilation Ducting."

Respectfully yours,

NOISE ATTENUATION IN STRAIGHT VENTILATION DUCTING

by

Thomas Lawrence Moore
Lieutenant, U. S. Navy

Henry Herbert Bell
Lieutenant, U. S. Coast Guard

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Submitted to the Department of Naval Architecture and Marine Engineering on May 20, 1957 in partial fulfillment of the requirements for the degrees of Naval Engineer and Master of Science in Naval Architecture and Marine Engineering

ABSTRACT

A method is developed for measuring the noise attenuation in ventilation ducting, and attenuation measurements are conducted on two sizes of standard ducting. The method utilizes a loudspeaker as a source and a condenser microphone as the acoustic measuring device.

A cylindrical wire mesh windscreen, used with the microphone for taking measurements in a moving air stream, is calibrated by employing a Y-shaped section of square cross section with acoustically similar legs. With air flowing in only one leg, sound pressure level measurements are made in octave bands in each of the legs of the Y at various air speeds, and the curves of self-noise generated by the windscreen are plotted. Using this windscreen calibration, sound pressure level measurements in frequency bands are made longitudinally along a standard duct; first, with air flowing and a centrifugal fan as the noise source, and second, with no air flow and a loudspeaker as the noise source. From plots of sound pressure level versus longitudinal distance the attenuation in each one-third octave band is determined in decibels per foot. Results obtained from the two methods are in close agreement.

Attenuation measurements are made on two different sizes

of standard bare ventilation ducting. The effect on attenuation of two types of externally applied glass mat thermal insulations is determined. The effect of increasing the ducting material thickness is investigated for one case.

It is concluded that noise attenuation in bare ducting is substantially higher in the two lowest and one highest octave bands than the 0.1 decibel per foot currently in use, and that the addition of externally applied thermal insulation greatly increases the attenuation characteristics over the first four octave bands. It is recommended that further measurements on various sizes of ducting be made to provide more accurate design data, and subsequent correlation of the variables involved.

Thesis Supervisor: Leo L. Beranek

Associate Professor of Communications Engineering.

ACKNOWLEDGEMENTS

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INTRODUCTION

With the increasing attention now being given the acoustical performance of ventilation systems, the design engineer is required not only to insure that a ventilation system meets thermal and air velocity standards but acoustical standards as well. At present a quantitative determination of the acoustical performance of a ventilation system in the design stage is difficult due to the lack of published information regarding the attenuation that unlined ventilation ducting will afford fan noise. Much more work, both theoretical and experimental, has been devoted to ventilation ducting lined with sound absorbing material. This data is available in the literature. The designer may also use any of several patented mufflers or silencers which are on the market, and for which attenuation characteristics are available. This situation usually results in the expensive procedure of lining ducting with sound absorbing material, or inserting a patented noise attenuator in the system to insure that acoustical standards are met.

The small amount of data available on noise attenuation in straight ventilation ducting is, in most instances, too general to allow a quantitative determination of the attenuation a system will afford fan noise having its own characteristic frequency spectrum. The recommended procedure for estimating attenuation in straight unlined ducts is to allow 0.05 decibel of sound pressure level* per foot of length in

*The reference pressure of 0.0002 microbar was used for all sound pressure level measurements made in this thesis.

ducts over 1 square foot in cross section, and 0.1 decibel per foot for ducts of lower cross sectional area.* These attenuation values are assumed to be independent of frequency. From some earlier experimental work** it appears that not only is the attenuation frequency dependent, as one would physically reason, but over certain frequency bands the attenuation may be substantially greater than the figure now in use.

In addition, the published data does not cover the region below 100 cps where the sound power of a fan is the greatest. This lack of information is due in part to the difficulties involved in providing an acoustical termination such that standing waves of frequencies in this region are sufficiently eliminated to allow accurate measurements. Another reason for the lack of information is the long length of ducting necessary to allow averaging of the remaining standing wave pattern such that false conclusions are not reached. In addition, the high self-noise generation of a windscreen used to enclose a microphone for sound measurements in moving air masks much of the noise one wishes to measure.

It is the purpose of this thesis to supply additional data on noise attenuation in unlined ventilation ducting. Because of monetary, space, and time limitations, and to

*American Society of Heating and Air Conditioning Engineers Guide. Chapter 40, "Sound Control", 1957

**Peistrup and Wesler, "Noise of Ventilating Fans" J. Acoust. Soc. Am. Vol. 25, No. 2, pp. 326, 1953
Wilber and Simons, "Determining Sound Attenuation in Air Conditioning Systems" Heating, Piping & Air Conditioning ASHVE Journal Section, pp. 317-321, 1942

eliminate as many of the variables as possible, it was decided to limit the investigation to straight ducting. This thesis establishes a method of noise attenuation measurement which can be later utilized to test the effects of turning vanes, bends, take-offs, etc. The investigation will be subdivided into three parts.

The first part is the calibration of a windscreen to allow noise measurements to be taken with a microphone in moving air. The second part is a comparison of the fan noise attenuation in a specific duct with moving air to the attenuation of noise from an electronic noise source and loudspeaker with still air. The proof that noise attenuation in still and moving air is the same is highly desirable, since it will permit the use of an electronic noise source-loudspeaker combination instead of a fan as the noise source. This eliminates the necessity of using the windscreen, whose self-noise in a moving air stream may be sufficient to mask the fan noise in some frequency bands. The third part is the measurement of attenuation in straight ducting using an electronic noise source and loudspeaker as the source of sound energy and a condenser microphone as the measuring device.

It was further decided to investigate the variation in attenuation in straight ducting attained by changing the gage of the metal used to fabricate the duct, and also the effects of thermal insulations which are frequently applied to the exterior of the duct. There is no data in the literature

regarding the effects of either of these variables. The authors feel that if these changes to the standard bare duct do appreciably increase the attenuation of noise such data would be valuable, since thermal insulation is applied to all ducts carrying heated or cooled air. The investigation of these variables is to be conducted in conjunction with the attenuation measurements of the bare ducting.

The noise attenuation is determined by measuring the sound pressure level in one-third octave-bands at intervals along the duct. A plot is made for each one-third octave-band of sound pressure level versus distance from the loudspeaker, and the slope of a line drawn through these points is measured. The slope is the attenuation in decibels per foot for the one-third octave-band plotted.

PROCEDURE

1. Windscreen Calibration

The first phase of the investigation was to determine the self-noise generated by a windscreen in moving air. This windscreen calibration was necessary because later sound pressure level measurements were to be made in moving air. The calibration then insured that the quantity measured was source noise, and not noise produced by the windscreen.

The calibration was conducted on the windscreen shown in Figure I. This is a 3" x 5" cylindrical windscreen for use with an Altec 21-BR-150 condenser microphone. Figure I also shows the relative size of the microphone-pre-amplifier combination, which is inserted into the windscreen adapter.

The system used for calibrating the windscreen is shown in Figure II. The basic premise of the method is that if the two legs of the Y are acoustically equal, the sound energy flowing into the Y will divide evenly between the two legs. To ascertain this similarity, white noise was supplied through a loudspeaker directed axially into the base of the Y, and octave-band sound pressure level measurements were made in the two legs.

With a fan connected to the system, all of the air flowing into the Y flows out of the "live" leg. The "dead" leg was terminated with a 12" x 12" wedge of 100 cycles per second cut-off frequency. The "live" leg had

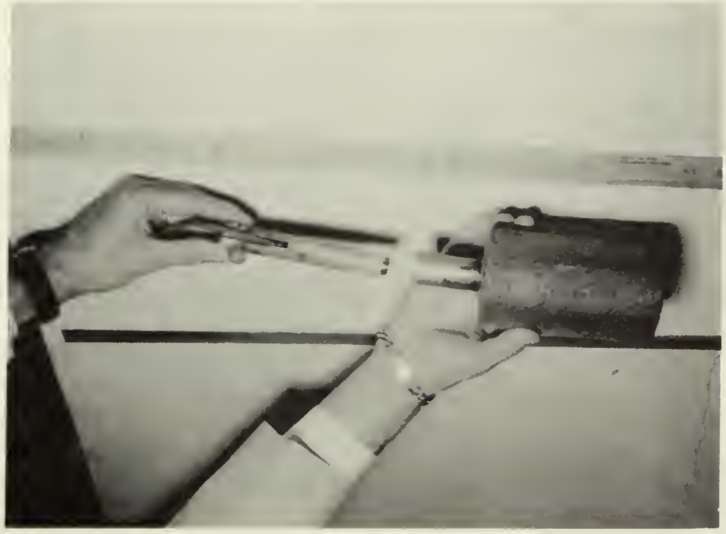

Figure I a. Windscreen, Microphone and
Pre-amp

Figure I b. Windscreen Mounted on Carriage

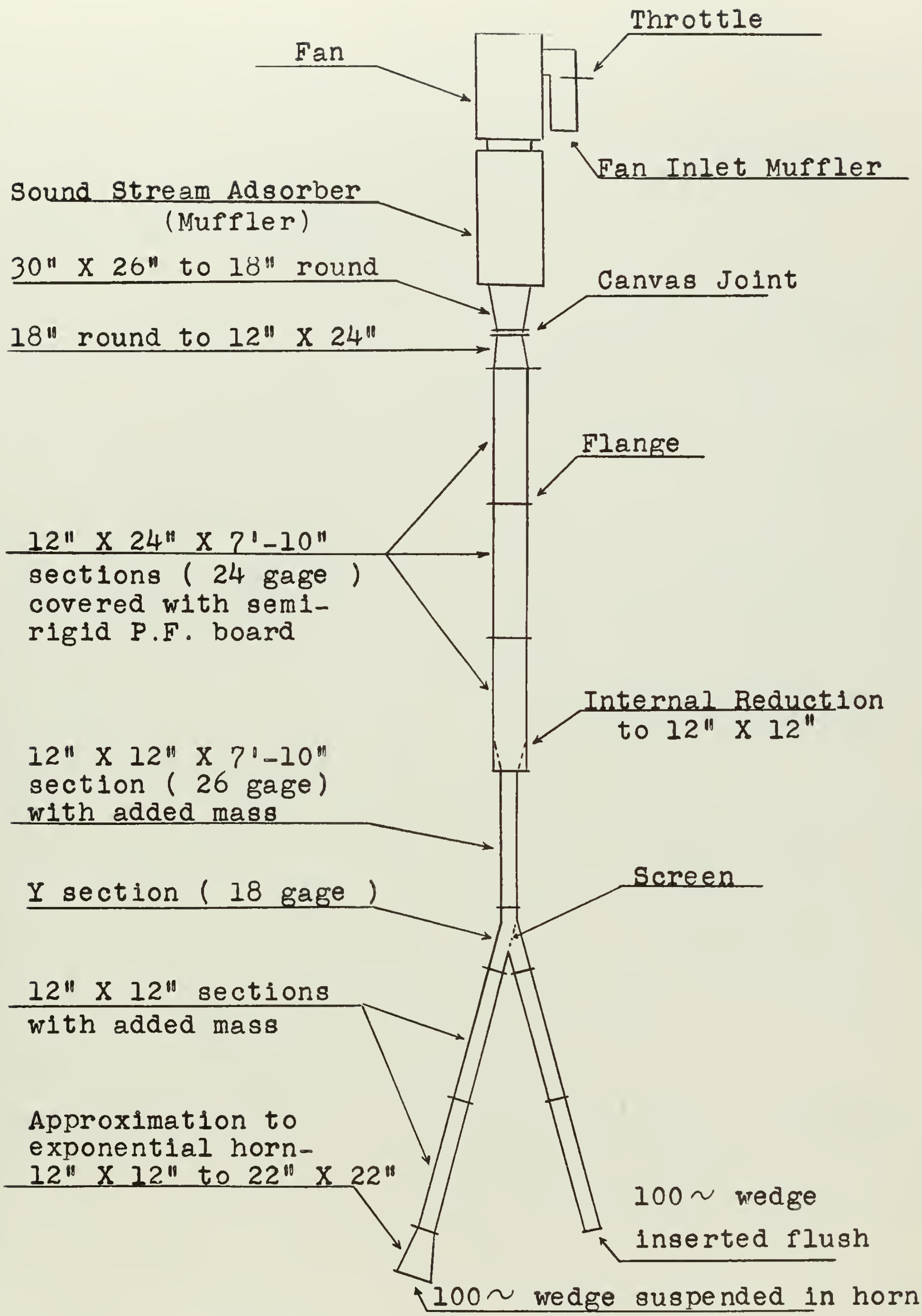

Figure II. System Used for Windscreen Calibration.

a similar wedge suspended in a plywood exponential horn. A fine wire mesh screen was stretched across the inlet to the "dead" leg. Its purpose was to decrease turbulence at the intersection of the two legs caused by re-entrant air circulation from the "dead" leg.

The microphone and windscreen were mounted on the moveable carriage shown in Figure I. Transverse guides were used to position the microphone at the center of the duct.

The fan is a two-speed centrifugal fan whose output is controlled by throttling the air inlet. At several different air speeds, sound pressure level measurements were taken in octave-bands in both legs. If the measured noise in the "live" leg exceeded that in the "dead" leg by greater than 6 decibels, the measured noise in the "live" leg was considered to be the self-noise generated by the windscreen at that particular air velocity. If the two measurements were within 6 decibels it was considered that the fan noise was too high to permit calibration of the windscreen in the particular frequency band using this method.

2. Effect of Air Flow on Attenuation

The second phase of the investigation was to determine the effect of air flow upon the noise attenuation characteristics of a duct. This was accomplished in two series of measurements, conducted on two sizes of ducting, one covered with thermal insulation and one bare. In the first investigation sound pressure level measurements were taken in one-third octave bands at three foot intervals longitudinally

down a straight bare duct for three conditions: (1) no air flow, white noise from a loudspeaker mounted axially at one end, (2) with air flow supplied by the fan and additional noise introduced through a loudspeaker mounted at the duct inlet perpendicular to the air flow, and (3) same conditions as in (2) above with a change in the rate of air flow. A plot of sound pressure level versus distance was plotted for each third octave-band. By superimposing the three curves, it was proved that the attenuation is essentially independent of air velocity.

The object of the second series of measurements was to verify that attenuation measurements made with the fan as the noise source, and utilizing the windscreen calibration previously obtained, are in agreement with those made with no air flow and the loudspeaker as the source. The muffler was removed from the system for the measurements taken with moving air. This was done in order to raise the noise level above the windscreen self-noise by at least ten decibels. Thus the effect of windscreen noise was negligible. Attenuation plots for the above condition were superimposed on similar plots taken with the loudspeaker as a source. The two methods yielded equivalent results.

3. Attenuation in Standard Ducting

The final phase of the investigation was to determine the noise attenuation in one-third octave bands for two sizes of standard ventilation ducting, 12" x 12" and 12" x 24". In Part 2 it was proved that air motion has no

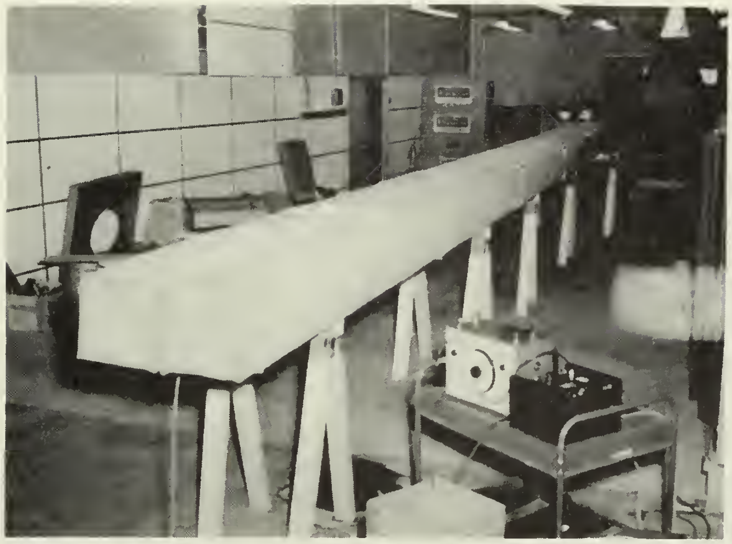

Figure III. 12" X 24" Ducting with Aerocor
Covering

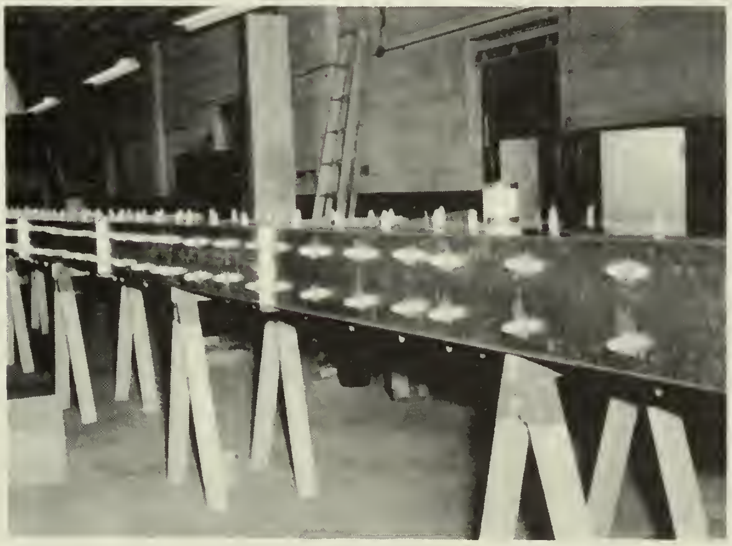

Figure IV. 12" X 24" Ducting with Clips for
Mounting P.F. Board

effect on the attenuation characteristics of a duct. Hence all measurements taken in this section were in still air, with the loudspeaker as a source. The ducting was supported by wooden saw horses, and a comparison between supporting at joints and supporting at panel centers was made.

The effect on noise attenuation of two conventional thermal insulations, Fiberglass Aerocor and Semi-rigid P.F. board, was investigated. These insulations were applied using "Stic Klips", a standard-type fastener used extensively in the trade. See Figures III and IV. The effect of the gage of the material was briefly investigated by coating the 12" x 12" standard duct with asbestos-based, plastic roofing cement. The mass of the ducting was roughly doubled by using an 1/8" coating of the cement.

In this section the essential steps in the procedure have been mentioned, while many of the equipment details and minor steps have been omitted. The reader is referred to Appendix A, Details of Procedure, for a more detailed discussion of the procedure and equipment.

RESULTS

The results are presented in graphical form in this section from the data appearing in Appendix C, Summary of Data.

1. Windscreen Calibration.

The windscreen calibration was performed on the three inch by five inch windscreen shown in Figure I. The results of the calibration are shown in Figure V, where the self-noise generated by the windscreen in decibels of sound pressure level is presented in octave-bands with velocity as a parameter.

Figure VI is a plot of the same data as presented in Figure V but is a semi-logarithmic representation of windscreen self-noise in decibels of sound pressure level versus the logarithm to the base ten of air velocity with frequency in octave-bands as a parameter. The purpose of this plot is to show that for a particular windscreen the self-noise is a function of air velocity to some power.

2. Effect of Air Flow on Attenuation.

The comparison of the attenuation of noise in moving air versus the attenuation of noise in still air was made in accordance with the methods outlined in the Procedure. The sound pressure level readings for each one-third octave-band are plotted against distance from the noise source. The results of this investigation are shown in Figure VII where the readings for both conditions are plotted. For ease of comparison the initial sound pressure level reading for each condition is taken as a base, and all other readings

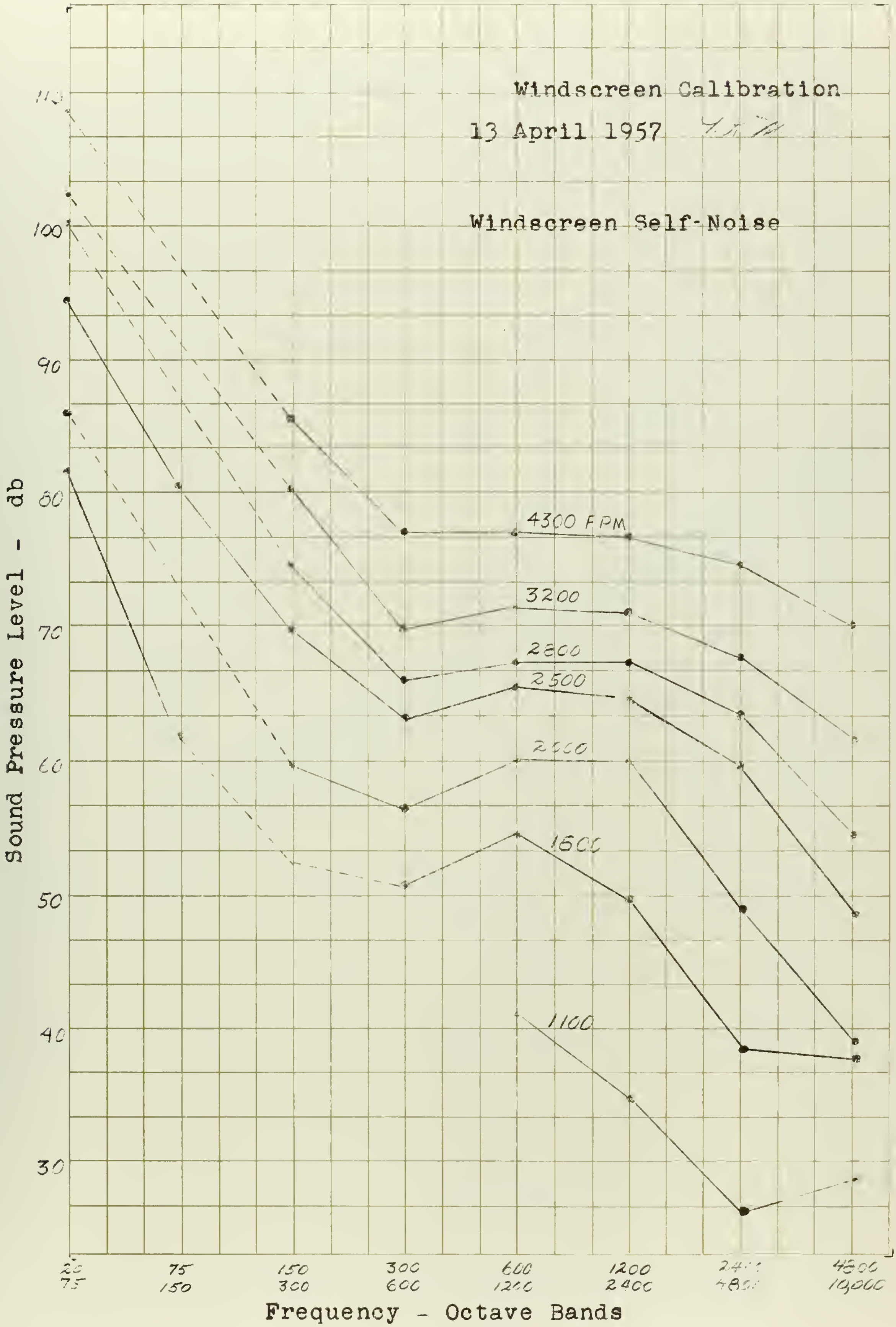

Figure V. Windscreen Calibration

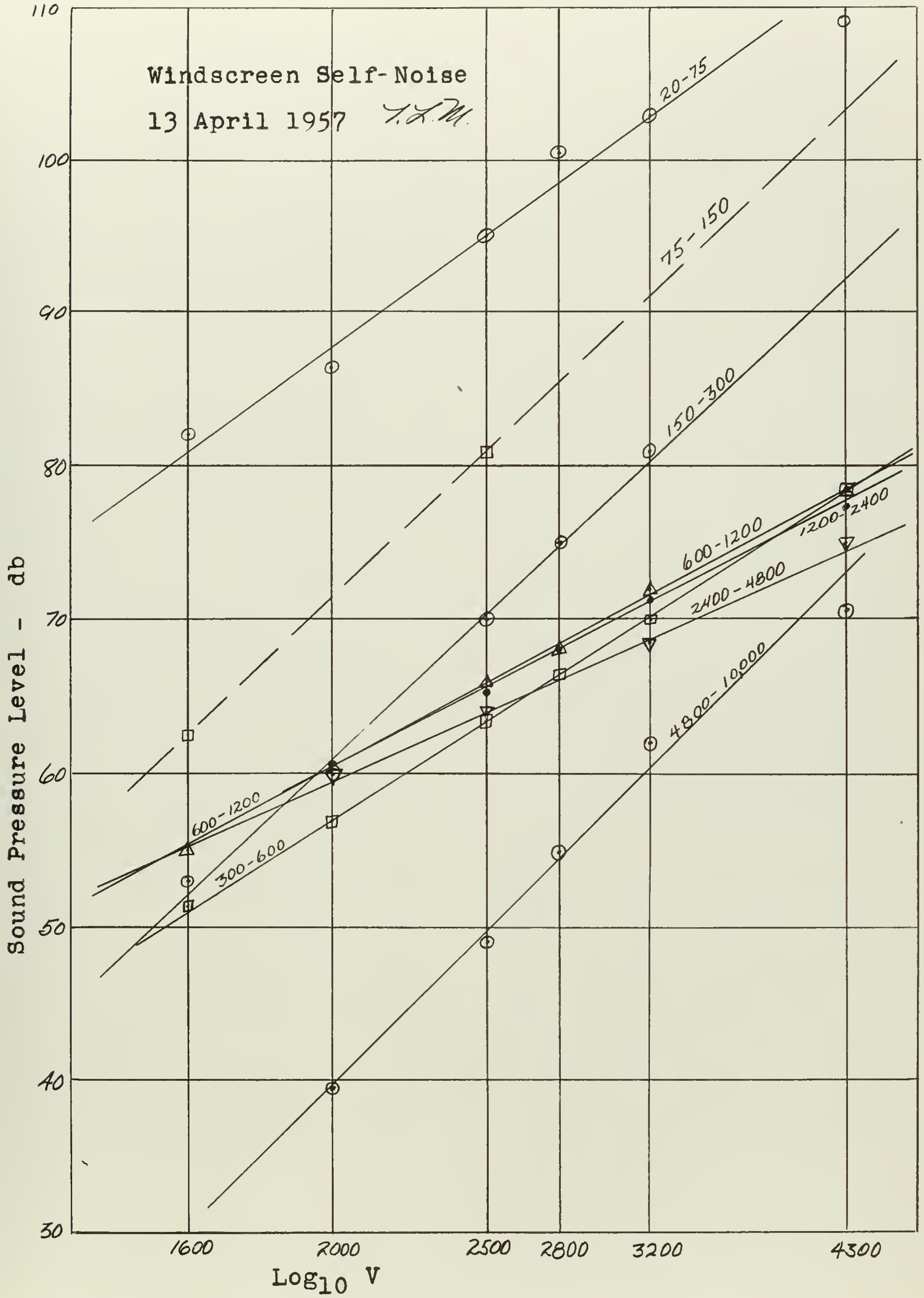

Figure VI. Logarithmic Plot of Windscreen Self-Noise

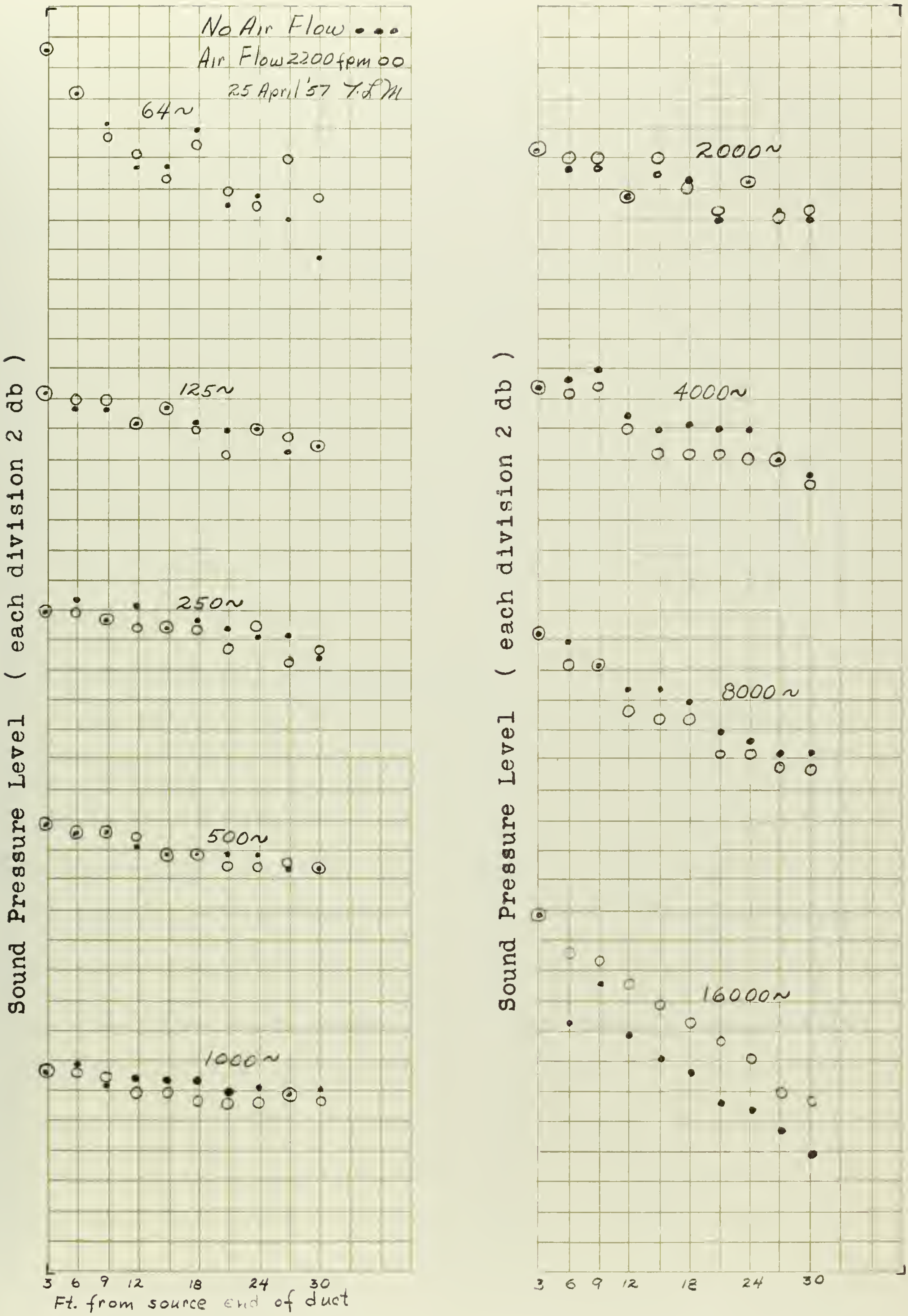

Fig. VII Variation of SPL with Distance in Still & Moving Air

within the same one-third octave-band for the same condition are plotted as deviations in decibels from this base. This procedure was necessary because it was impossible to insure that the sound power in each one-third octave-band was the same for both conditions.

To further verify that the attenuation was the same with still and moving air, a comparison of the attenuation to fan noise with moving air versus the attenuation to loud-speaker noise with still air was made as outlined in the Procedure. The results of these measurements are shown in Figure VIII where the attenuation in decibels per foot in one-third octave-bands for the two conditions investigated is presented for comparison.

3. Attenuation in Standard Ducting.

The third part of this thesis was the measurement of noise attenuation in standard ventilation ducting. The attenuation, in decibels of sound pressure level per foot, was determined as previously outlined. The results of the investigation conducted on the 12" x 12", 26 gage, length of ventilation ducting are shown in Figures IX and X. The first of these plots is a comparison of the attenuation in bare ducting with that measured for the same duct covered with two different types of thermal insulation. The second plot illustrates the effect of adding mass to the ducting. The added mass was plastic roofing cement, but the results are indicative of the effect of increasing the gage of the metal.

Figure XI shows the results of investigations conducted

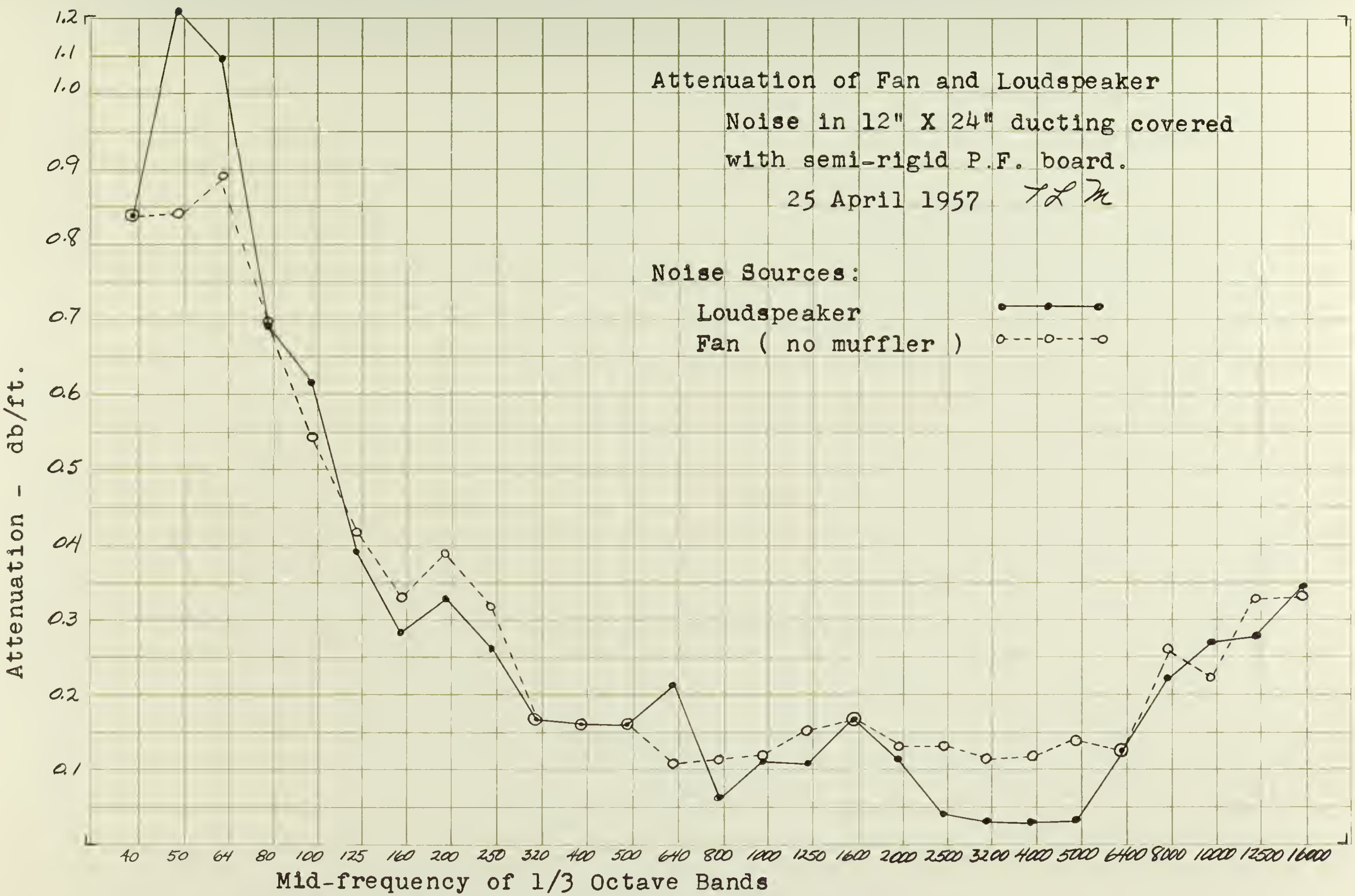

Figure VIII. Comparison of Attenuation in Still and Moving Air

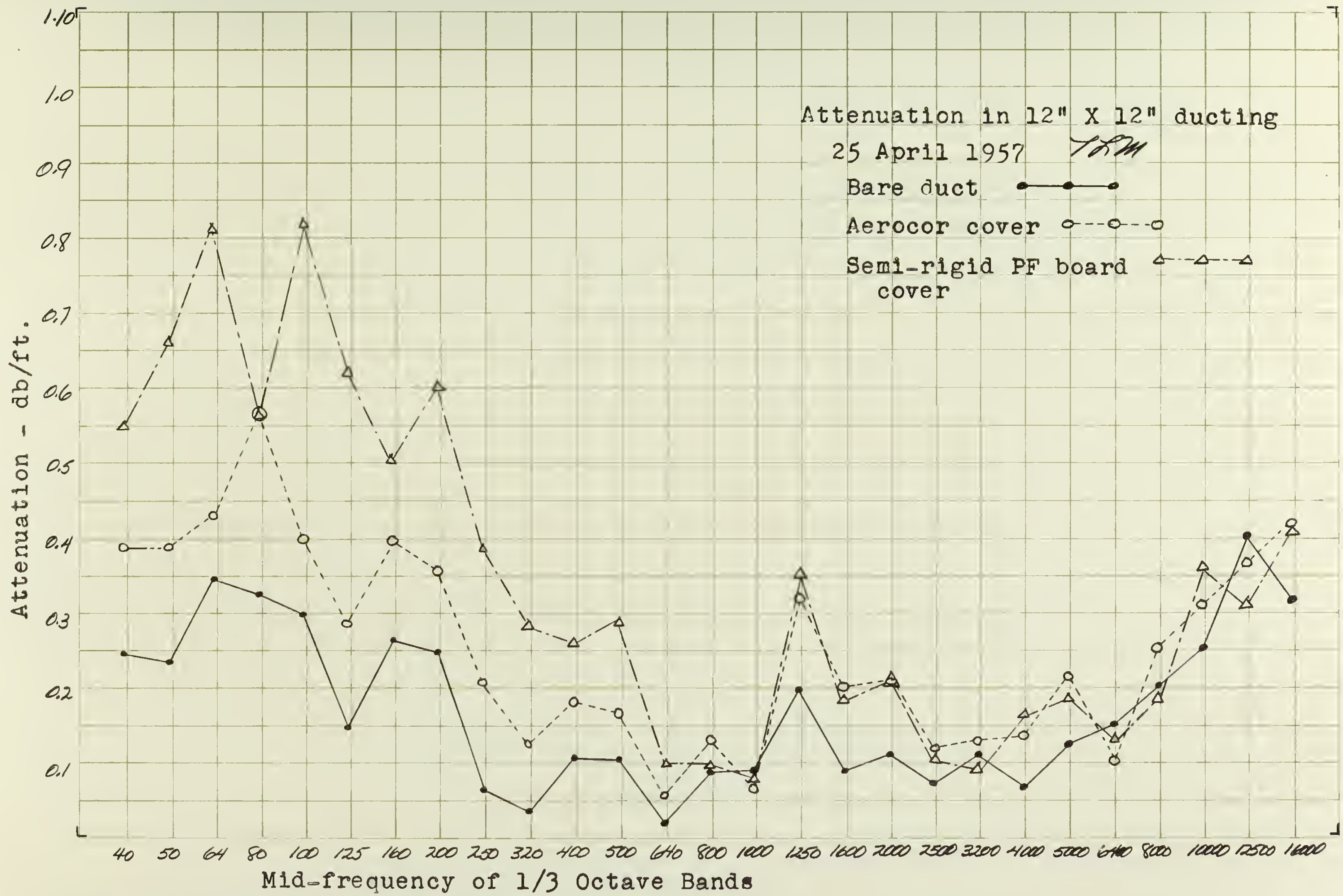

Figure IX. Attenuation in 12" X 12" Ducting.

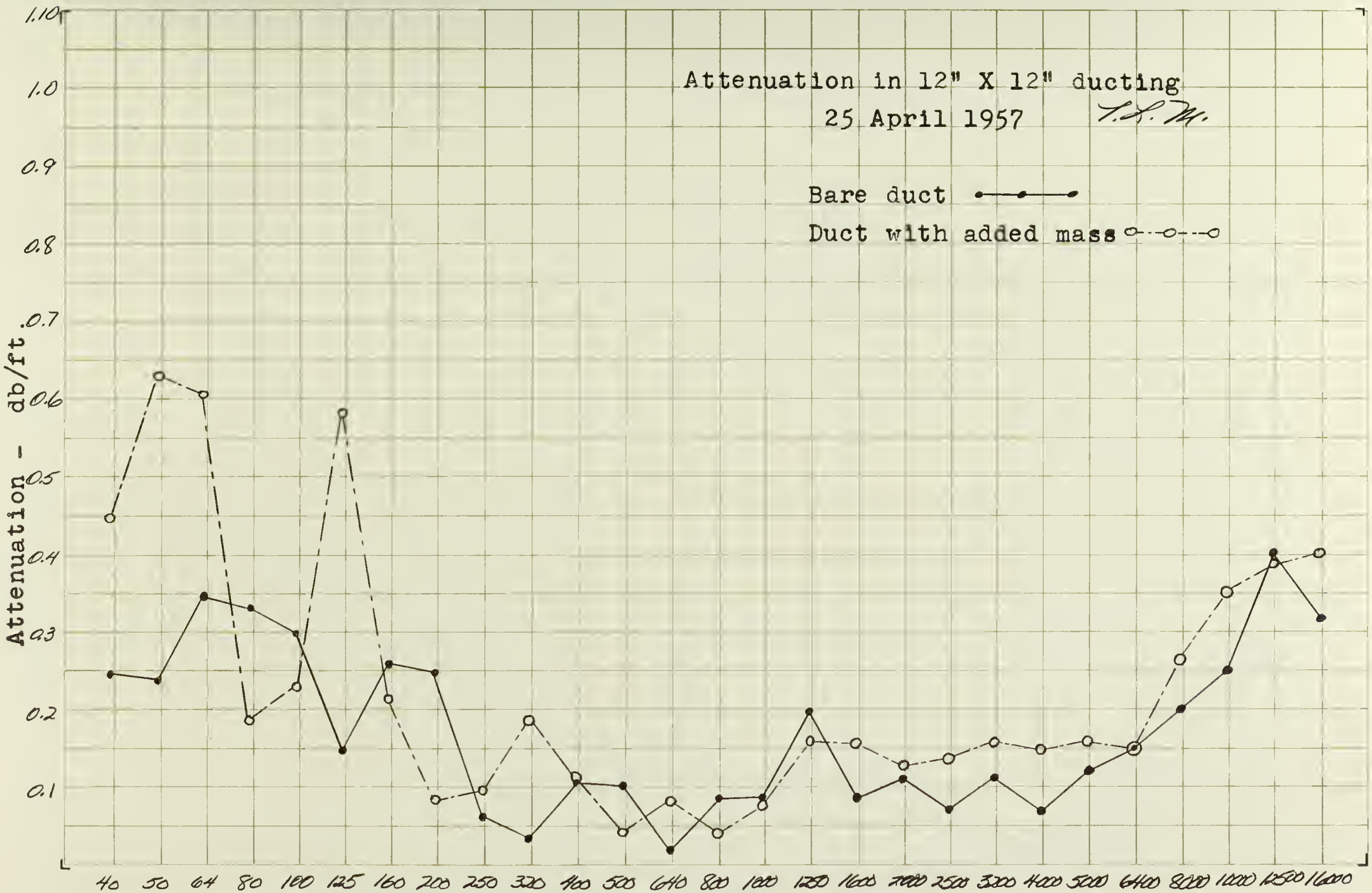

Figure X. Effect of Added Mass on 12" X 12" Bare Duct Attenuation.

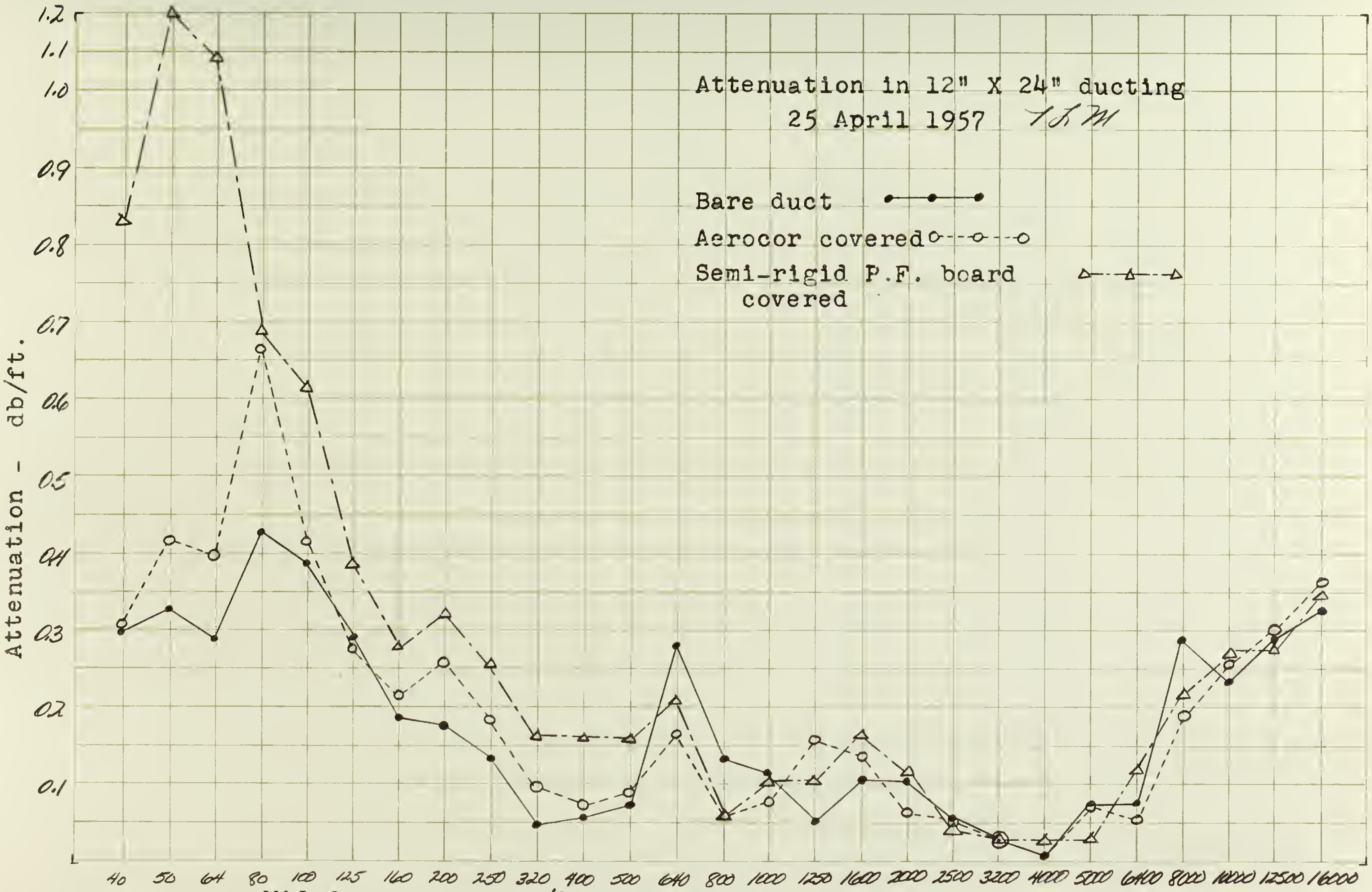

Figure XI. Attenuation in 12" X 24" Ducting.

on a 12" x 24" length of standard 24 gage ducting. This plot shows the bare duct attenuation and the variation of attenuation when two types of thermal insulation were attached to the exterior of the duct. Figure XII is a comparison of the bare duct attenuation for the 12" x 12" and 12" x 24" standard ducts.

The effect of supporting the ventilation duct at the joints and at the center of a length was investigated for the 12" x 12" and the 12" x 24" ducts. The types of plot used to determine the effects of the variation in support of the duct on the attenuation is illustrated by Figure XIII.

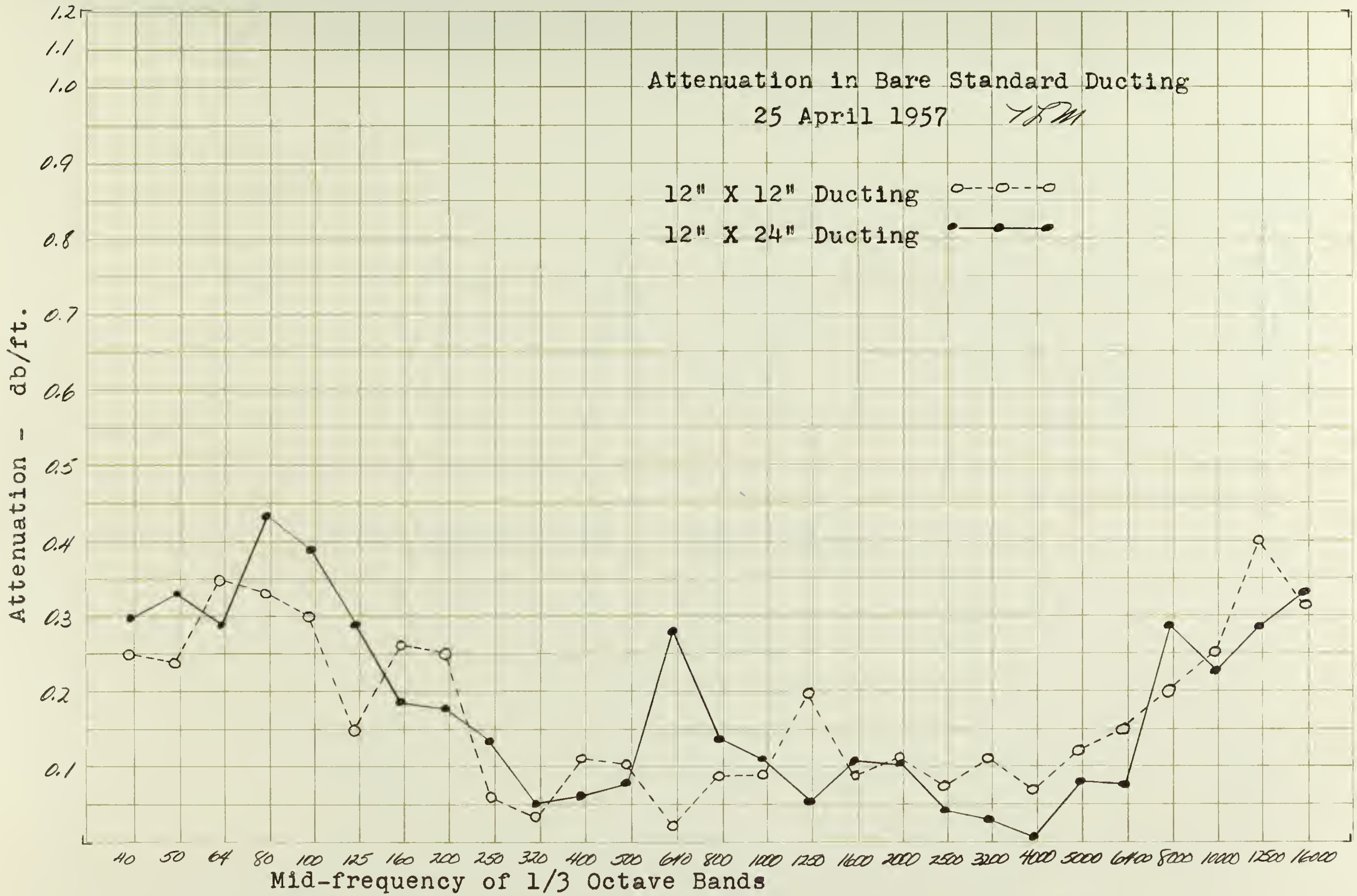

Figure XII. Comparison of Attenuation in 12" X 12" and 12" X 24" Bare Duct.

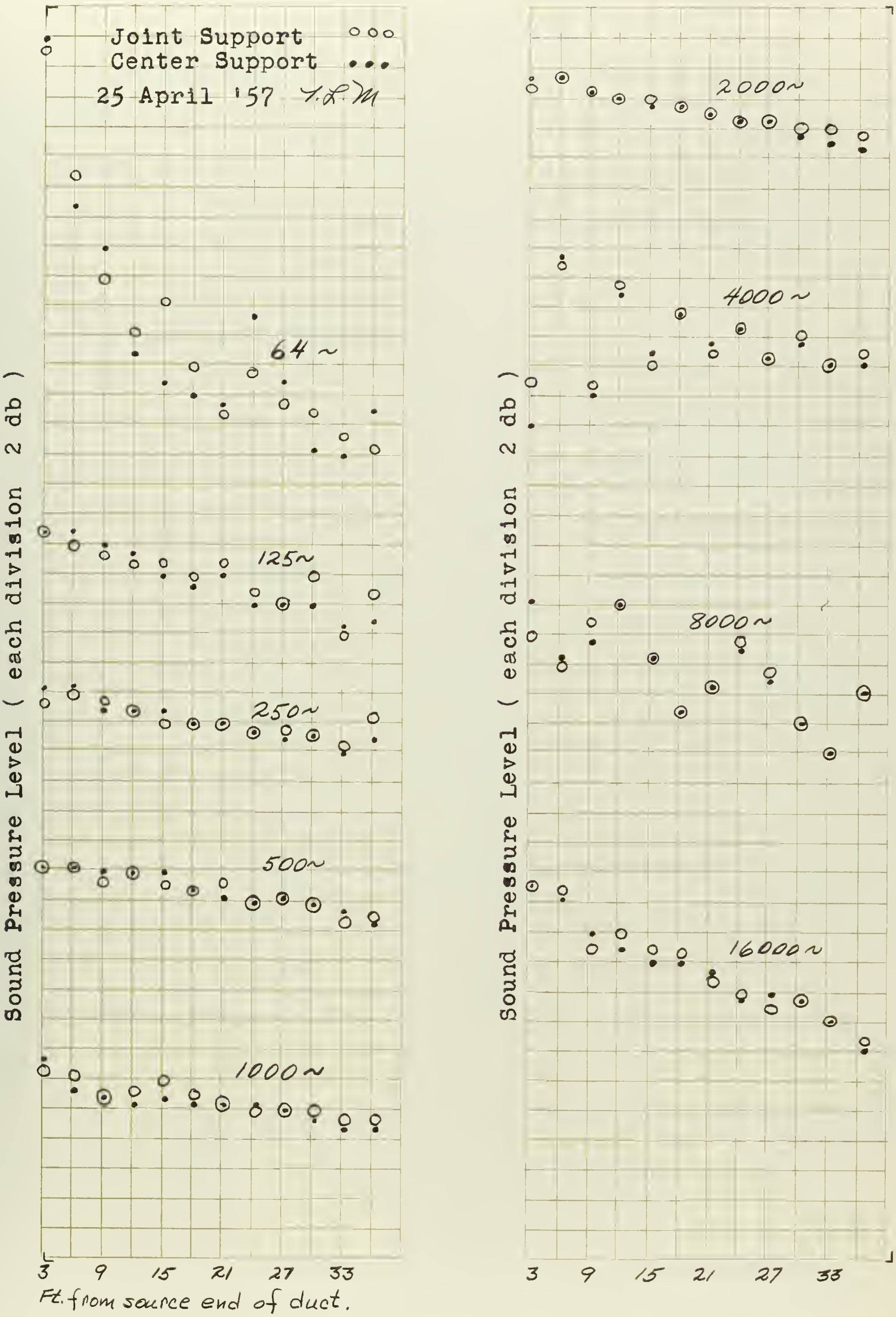

Figure XIII. Effect of Support on Attenuation

DISCUSSION OF RESULTS

The discussion of results is subdivided into three sections, each covering a separate phase of the thesis as outlined in the Introduction. In the following discussions, one-third octave-bands are designated by their mid-frequencies.

1. Windscreen Calibration.

Figure V shows the results of the windscreen calibration. Windscreen self-noise is plotted in octave-bands with velocity as a parameter. Solid lines connecting points show the shape of the curve with the windscreen noise at least 6 decibels above air born noise. Dashed lines are the probable shape of the curve in regions where data was unobtainable due to high fan noise, or indicate that the curve passes through a point whose magnitude is only between 5 to 6 decibels above the fan noise. These latter points were included even though they violate the 6 decibel criteria because they aid in showing the general level of windscreen self-noise in the octave-band for which used. It will be noted that in the instances where such data is used, the curves of self-noise follow the same general shape as the curves established by the reliable data.

The lack of data in the 75 - 150 cps and the 150 - 300 cps octave-bands is attributed to the high fan noise encountered in this region. As explained previously in this thesis, the fan employed was a two-speed centrifugal fan with air velocity control affected by throttling the air inlet. Thus, even with the Soundstream Absorber inserted

after the fan, the noise level did not decrease with air velocity. As a result, at the lower air velocities the noise level was too high to permit determination of the windscreen self-noise.

Figure VI is the same data as presented in Figure V but in the form of a cross curve, with sound pressure level for each octave-band plotted versus the logarithm to the base ten of the air velocity. These curves show that windscreen self-noise in octave-bands is a function of the air velocity to some power.

$$SPL = K\ V^n \tag{1}$$

Table I, shown below, has been prepared to give the values of K and n for each octave-band.

TABLE I

Values of K and n for each octave-band for use with equation (1),

$$SPL = K\ V^n,$$

the sound pressure level of windscreen self-noise in decibels equals a constant times the air velocity in feet per minute raised to the power n.

Octave-Band	n	K
20 - 75	.33	7.1
75 - 150	.51	1.46
150 - 300	.58	7.2
300 - 600	.44	2.0
600 - 1200	.36	3.9
1200 - 2400	.35	4.2
2400 - 4800	.30	6.0
4800 - 10,000	.89	0.43

It is not intended that the windscreen data will be used in the form presented by Figure VI or Table I. It is intended rather that the data will be used as presented in Figure V. To use this calibration one must measure the wind velocity and take sound pressure level readings in octave-bands (for the duct under investigation), employing the described windscreen-microphone combination. The sound pressure level obtained for the octave-band under consideration should be compared to the value shown in Figure V. If the measured value exceeds that of Figure V by 10 decibels, one may be reasonably assured that the sound pressure level measured is only a function of the sound power, and is not affected by windscreen self-noise. It must be remembered in using this data that it was obtained using a particular windscreen-microphone combination. Extreme care should be employed in applying the results to other windscreen-microphone combinations, since both the covering on the windscreen and the relation of the enclosed volume of the windscreen to the volume occupied by the microphone are factors relating to the effectiveness of a windscreen.*

A review of the literature shows that very little information on windscreens has been published. Leonard calibrated a 3" x 5" windscreen covered with silk by whirling the microphone-windscreen combination in an anechoic chamber.** The calibration was performed at two velocities, 1680 and

*Leo L. Beranek, "Acoustic Measurements", p. 258, John Wiley & Sons, Inc., 1949.

**Peistrup and Wesler, "Noise of Ventilating Fans", J. Acoust. Soc. Am., Vol. 25, March, 1953.

1140 feet per minute. Leonard's calibration for the higher velocity is plotted in Figure XIV. The curve is essentially linear, falling off at 6 decibels per octave. No peaking or leveling off, such as our results show, is noted.

Data published in another report* shows that for the 1" x 10" and 2" x 10" windscreens tested at several velocities, the same shape of curve as those in Figure V was obtained. In general the testing velocities in the above report and in this thesis work were higher than those at which Leonard's measurements were made. Figure XIV presents in graphical form a comparison of the above results with those obtained in this investigation.

2. Effect of Air Flow on Attenuation.

The type of plot used for comparison of the attenuation in the ventilation ducting with and without moving air is shown in Figure VII. This plot was made by taking the one-third octave-band readings closest to the noise source as base values for the condition under investigation and plotting all other readings for the same condition as deviations from these base values. Thus the first points on the plots of sound pressure level readings in a one-third octave-band for the conditions investigated always coincide. This procedure was employed since it was impossible to establish the same initial sound pressure level reading for each condition. If the initial reading was in error, the effect is to shift

*"Self Noise of Circularly Cylindrical Windscreens", Bolt, Beranek, and Newman Report No. 255, 30 August 1954.

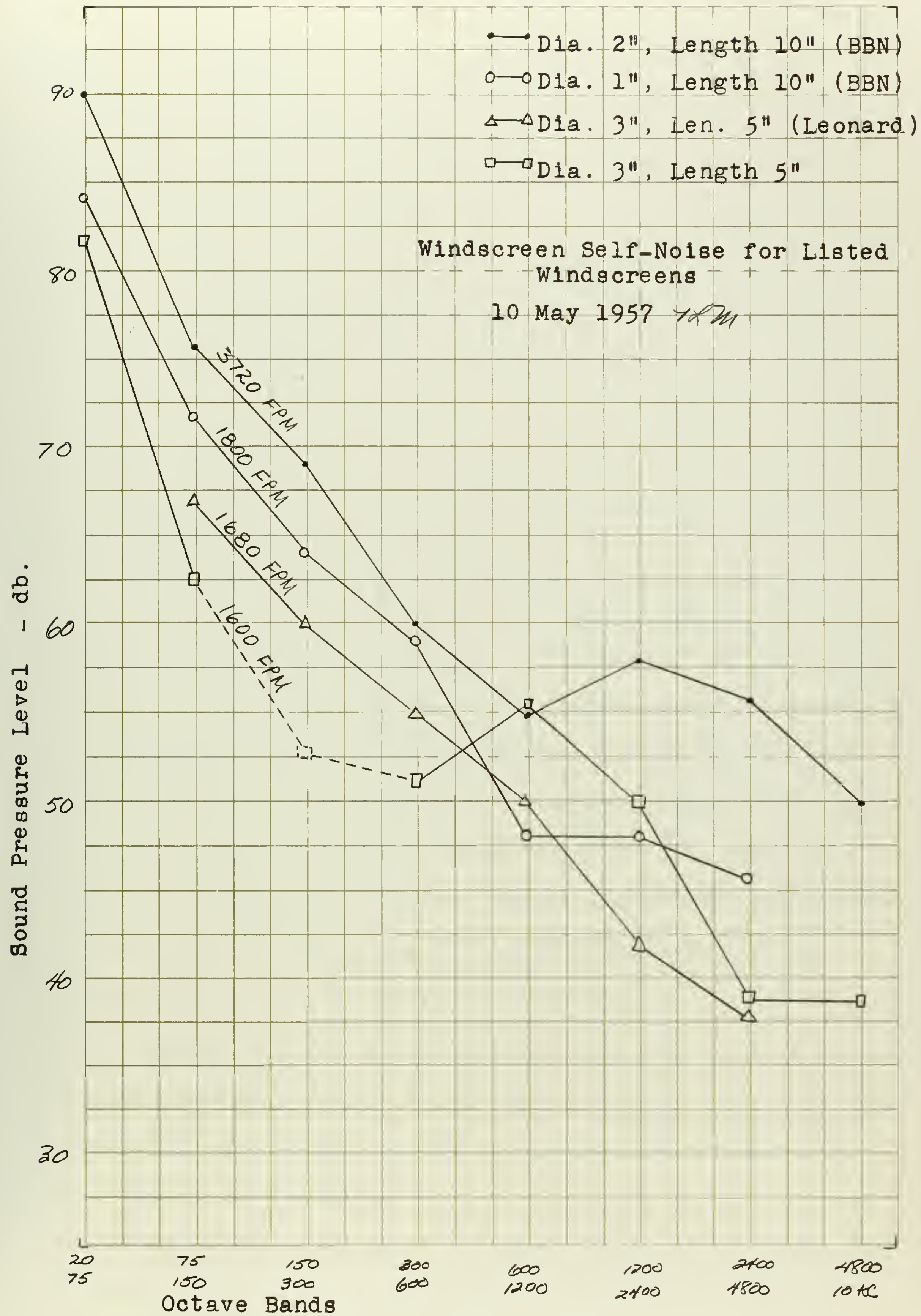

Figure XIV. Comparison of Various Windscreen Calibrations

the whole series of readings using it as a base. It is still possible to adjudge if the attenuations are the same.

With the equipment used for measuring sound pressure level in this thesis the best accuracy attainable was considered to be $\pm$ 0.5 decibels. In the lower one-third octave-bands this accuracy was never realized due to rapid fluctuations in the sound pressure level. In these regions the accuracy of the measurements depends upon the experience and skill of the person making the readings. Thus for the type of comparison of data illustrated by Figure VII, one must bear in mind the accuracies of the measurements involved when comparing individual readings.

The type of comparison illustrated by Figure VIII is less dependent upon the accuracy of a single reading. This is a plot of the attenuation in one-third octave-bands where the attenuation is measured by passing a line through the sound pressure level readings for a single one-third octave-band plotted versus distance down the duct, and the slope of the line determined. Since ten or eleven sound pressure level readings are involved in the determination of the attenuation for each one-third octave-band, an error in a single reading is easily recognized. The accuracy is also improved since the errors within the accuracy limits of the measurements are random in nature and should average out with a number of readings.

Comparing the attenuation to fan noise with moving air and the attenuation to loudspeaker noise in still air, as shown in Figure VIII, it is seen that the two are in close

agreement except for two regions. Below the 100 cps band the duct would appear to offer less attenuation to fan noise with air flow than loudspeaker noise with no air flow. This was adjudged not to be true, as explained below.

The fan used for this comparison, and described elsewhere in this thesis, had an unbalance such that a large amount of low frequency energy was imparted to the air. This energy caused the overall sound pressure level, measured from 20 cps to 10,000 cps, to be between 10 and 20 decibels above the lower frequency one-third octave-band sound pressure level readings. The lowest third octave-band mid-frequency is 40 cps. In addition it caused panting of the duct walls at an estimated frequency of 5 cps. This panting was aggravated by throttling the air intake, which was necessary to reduce the air velocity such that windscreen self-noise was at least 10 decibels below fan noise. As a consequence the lower one-third octave-band sound pressure level readings were extremely difficult to obtain. This fact, plus the absence of a plausible explanation of why the attenuation should be different for the two conditions below 100 cps when it was the same for the rest of the third octave-bands, leads to the conclusion that the attenuation is essentially the same as that for the no air flow condition.

In the frequency bands between 2000 and 6400 cps it would appear that the reverse phenomenon to that observed below 100 cps exists, i.e. that the attenuation in still air is less than with moving air. However, a strong, confused

transverse wave pattern existed in this region for the duct under consideration. The wave pattern not only varied transversely but longitudinally as well. The extreme amount of longitudinal variation that this type of transverse wave pattern possessed is illustrated in Figure XV, Appendix C. This figure is based on measurements made on the 12" x 12" duct, where the same phenomenon, but of a less violent nature, was experienced.

With such longitudinal variations in the transverse wave pattern, one cannot expect that the readings taken every three feet would average this variation when plotted for the attenuation determination.

Such an average was obtained with air flow due to the aforementioned panting of the duct walls. Since the transverse wave pattern is a function of the geometrical configuration of the cross section of the duct, the panting of the duct walls caused a shifting of this wave pattern. Thus the transverse wave pattern varied cyclically with duct wall panting, and was distorted in a varying manner due to the random turbulence of the air flow. In addition there was some vertical movement of the microphone and carriage due to the movement of the duct wall supporting them. These three effects produced an averaged sound pressure level reading, more indicative of the sound pressure level existing in the cross section. It was concluded therefore that the sound pressure level readings obtained with air flow in the frequency region under discussion are more indicative of the true attenuation

one would observe.

The conclusion is thus reached that the attenuation of noise by ventilation ducting is independent of air velocity and of the nature of the noise source.

3. Attenuation in Standard Ducting.

From the curve of attenuation for the bare 12" x 12" ducting, Figure X, one may observe that the attenuation is approximately 0.1 decibels per foot for the frequencies between 250 cps and 5000 cps only. In this region it should be noticed that the size of the duct influences the attenuation. Thus the one-third octave-band containing the fundamental transverse frequency attains a higher than average attenuation. The frequencies of the fundamental transverse waves are 565 cps for the two foot dimension and 1130 cps for the one foot dimension, under conditions of normal temperature and pressure. Above and below the region between 500 cps and 2500 cps the attenuation rises, increasing to roughly 0.3 decibels per foot for the lower frequencies, and to roughly 0.35 decibels per foot for the higher frequencies.

Comparing the attenuation obtained with the duct externally coated with plastic roofing cement to that it possessed when bare, little change is noted above the 320-400 cps region. From this the conclusion is drawn that the attenuation of noise above the twelfth one-third octave-band is not significantly influenced by the mass of the duct walls.

Excluding the regions where transverse resonance is present, the attenuation above the twelfth one-third octave-band is concluded to be the normal attenuation of noise in air. Published data* indicates that for the 30% relative humidity, 70°F temperature conditions which existed when attenuation measurements were conducted, the attenuation due to air is 0.152 decibels per foot at 4000 cps and 0.52 decibels at 10,000 cps. These attenuations are in close agreement with the values measured.

Below 400 cps a change in the attenuation is observed when the exterior coating is applied to the bare duct. There is a lowering of the frequencies at which the resonance peaks occur, as would be expected with increased panel mass. The attenuation is in general greater than that of the bare duct, with the greatest attenuation at the points of resonance. This indicates that the energy dissipation does not obey the mass law, but is in the form of a frictional dissipation in the covering material and duct walls.

It will be observed that wrapping the bare duct with glass-mat thermal insulation does not change the attenuation characteristics above 2500 cps. This verifies the conclusion that in this region attenuation is not a function of the duct panel mass. The attenuation obtained at the fundamental transverse frequency, 1130 cps, is increased by 0.13 decibels per foot over that obtained with bare ducting. There is no fre-

*Leo L. Beranek, "Acoustics", pp. 310-311, John Wiley & Sons, Inc., New York, 1954.

quency shift observable due to mass, though this shift may have occurred within the one-third octave-bands measured. The attenuation peak at 80 cps may be attributed to panel resonance, with the glass-mat providing the additional frictional dissipation. Thus it may be concluded that the glass-mat was light enough to produce no observable shift in frequency but that the frictional dissipation of energy caused by its addition increases the attenuation below 500 cps by about 0.1 decibels per foot.

Attaching semi-rigid glass board to the duct causes no change in the attenuation above 2500 cps, as is predicted by the previous discussion. Also one may observe that in the one-third octave-bands containing the fundamental transverse frequency, the attenuation is the same as with wrapped glass-mat. Below 640 cps there is an increase in attenuation of about 0.26 decibels per foot from that observed with the bare duct, being even greater in some bands. These attenuation peaks do not follow the same pattern as with the bare and wrapped duct, and it is difficult to conclude any more than that a frequency shift did occur which is detectable in some one-third octave-bands and not in others.

The attenuation of noise by the 12" x 24" bare duct, Figure XI, has the same shape curve of attenuation in one-third octave-bands as was measured for the bare 12" x 12" duct. In addition, the magnitudes of the attenuation in one-third octave-bands are approximately the same for the two ducts. The comparison is shown in Figure XII. Two

differences are to be noted; the two foot transverse wave produces a peak at 640 cps while the one foot transverse wave produces a hollow at 1250 cps, and in the one-third octave-bands of 3200, 4000, and 5000 cps the attenuation is very low, averaging 0.16 decibels per foot less than observed for the bare 12" x 12" duct. The decrease in attenuation is attributed to the confused transverse wave pattern at this frequency. This phenomenon has been discussed previously in connection with the attenuation comparison of fan noise and loudspeaker noise, with the conclusion that the actual attenuation one would encounter in these frequency bands is about 0.07 decibels per foot higher than indicated.

The wrapping of the 12" x 24" duct with glass-mat thermal insulation increases the attenuation below 500 cps compared to that measured for the bare duct. It does not change the shape of the curve of attenuation in one-third octave-bands in this region, only increasing the magnitude of the attenuation between 0.02 to 0.04 decibels per foot, depending upon the frequency.

It is to be noted that above 2500 cps there is no change in attenuation due to the glass-mat, as has been observed for all the results discussed. In the 500 to 2500 cps region the attenuation is reduced at the frequency of the two foot transverse standing wave and increased at the frequency of the one foot transverse standing wave.

As has been observed previously, addition of the semi-rigid glass board does not change the attenuation above

2500 cps. Below 500 cps the attenuation is increased between 0.08 decibels per foot at 500 cps and 0.81 decibels per foot at 64 cps. No frequency shift of the resonance peaks is observable as were noticed when the cement coating and the semi-rigid glass board were added to the bare 12" x 12" ducting.

The conclusion which is drawn from the investigation of the variation of noise attenuation with support conditions is that supporting the duct at the joints or at the centers of the duct sections does not affect the attenuation. The type of supports employed during this investigation were adopted to simulate the type of support ducting would have from "U" shaped strap hangers. Thus ducting supported in this manner should give a close approximation to the attenuation measured in this thesis.

This conclusion should not be extended to other support conditions for it is obviously possible to support the duct such that sufficient restraint of duct paneling results, thus changing the attenuation.

CONCLUSIONS

From the investigations conducted in this thesis, the authors draw the following conclusions:

1. The self-noise generated in an air stream by the particular type of windscreen tested is an exponential function of the velocity. The form of the equation is,

$$SPL = K\ V^n$$

where K and n are different for each octave band.

2. The attenuation of noise in ventilation ducting is independent of air velocity and of the nature of the noise source.
3. The attenuation of noise in ventilation ducting is essentially independent of the mass of the duct walls above about 500 cps. Below this frequency the frequencies at which resonances occur are lowered, and the magnitude of the resonances are increased by an increase of the duct wall mass.
4. For frequencies below about 500 cps, the addition of thermal insulation to the exterior appreciably increases the attenuation properties of the duct.
5. The attenuation characteristics for standard ventilation ducting of 12" x 12" and 12" x 24" cross section are essentially the same.

RECOMMENDATIONS

The following recommendations for further study in the area covered by this thesis are made:

1. Conduct attenuation measurements on other sizes of standard ventilation ducting. The ultimate goal would be a family of curves for use in design work.
2. Expand the testing method developed in this thesis to measurements on the effect of take-offs, turning vanes, bends, etc.
3. More thoroughly explore the effect of mass on the attenuation in ducting.
4. Conduct further tests on the effect of various thicknesses and densities of conventional thermal insulations.
5. Utilize the windscreen calibration to take attenuation measurements in an installed ventilating system.

APPENDIX

APPENDIX A

DETAILS OF PROCEDURE

The basic steps in the procedure are discussed in Part II of the main body of the thesis under PROCEDURE. In this section of the Appendix details of the apparatus and all of the steps, many of which were not important enough to be mentioned in the main body of the thesis, are examined.

1. Windscreen Calibration.

The first installation used to calibrate the windscreen was that shown in Figure XVI. Note that one length of bare 12" x 12" standard ducting was used between the transition piece and the Y. Later three lengths of 12" x 24" covered ducting were added. This installation is shown schematically in Figure II. The additional length with its Fiberglas covering was used for greater attenuation of the fan noise, primarily in the low frequency bands. With the fan noise further reduced, it was possible to achieve a 6 decibel difference between fan noise and windscreen generated self-noise for a greater number of frequency bands. Hence a more complete calibration was attained.

a. Description of System

All straight ducting used was of standard gage and in standard lengths as recommended by the Society of Heating and Ventilating Engineers Guide. The standard duct is made from a sheet of metal 8 feet long. For our purposes the length was shortened two inches by bending a one inch flange at each end. A different type of joint is often used to

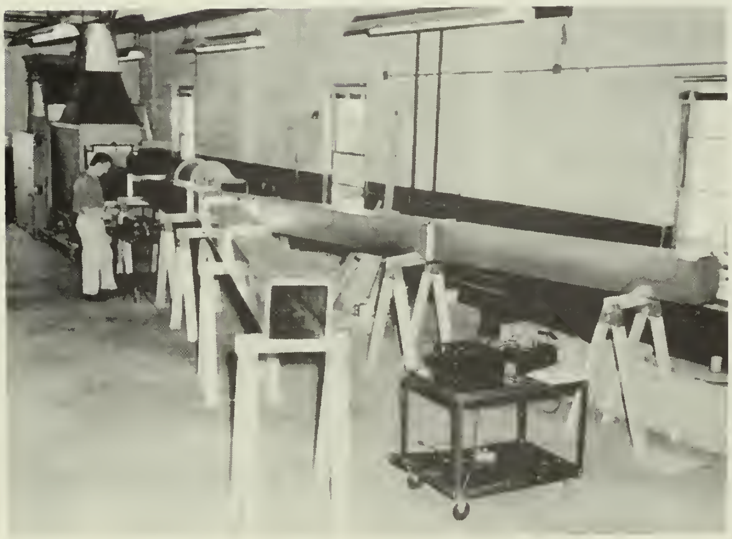

Figure XVI. System Used in Preliminary
Windscreen Calibration

permanently join ducting; however the effective length is still 7 feet 10 inches. The 12" x 12" ducting was constructed of 26 gage galvanized iron, while the 12" x 24" sections were of 24 gage.

The transition piece between the fan muffler and the first section of ducting, and the Y section were constructed of heavier gage material. The Y was made of 18 gage metal to provide greater rigidity at the turbulent area. Bolts were used to join all sections, and ordinary weather-stripping felt was inserted between flanges for isolation and sealing. The entire length of ducting was supported on saw horses made of 2" x 4" lumber.

The fan used to supply air is a 21 inch Sturtevant centrifugal fan. Its noise output was reduced appreciably by discharging through the Soundstream Absorber shown in Figure II. This muffler also functioned to smooth the air flow. The purpose of the canvas section at the end of the transition piece was to isolate the structure-borne noise of the fan from the ducting system.

The windscreen used throughout the experimental work is shown in Figure I. It consists of a hollow cylinder 3 inches in diameter and 5 inches long made of perforated sheet metal and tightly covered with a very fine copper screen. This screening has approximately 200 wires per linear inch, and is characterized acoustically as a 2.46 rayl impedance. The Altec 21-BR-150 condenser microphone, which was used for all sound level measurements, screws into its preamplifier

and the two are inserted through the threaded adapter attached to the windscreen. See Figure I. When correctly inserted, the microphone is centered in the windscreen cylinder. For our purposes, both were mounted on the plywood cart shown in Figure I, so that the microphone was centered in the duct.

It was first necessary to determine the attenuation characteristics of the screening used in the Y section. This was accomplished by placing a 12 inch conical loudspeaker at the inlet to the system, supplying white noise from a signal source to the speaker, and taking sound pressure level measurements in octave-bands in the two legs. By this method it was determined that the screening in the Y is acoustically transparent. Likewise measurements were made within the duct and in free field to prove that the windscreen is also acoustically transparent. The latter proof was conducted using white noise, and later verified with pure tones. The fact that both screens were found to have no attenuation was advantageous, although not absolutely necessary, since attenuation correction curves were not required.

We next launched into the problem of terminating the two legs such that (1) acoustic equality of the two legs was assured, (2) air flow in the live leg was not restricted, and (3) standing waves in the lower frequency bands were minimized. Measurements were made with 12" x 12" wedges of 100 cps cut-off frequency inserted in both legs. The results were encouraging enough that an exponential horn was con-

structed of 3/4" plywood. The wedge was then partially inserted in the horn leaving 144 square inches between wedge and horn for air flow out of the "live" leg. With white noise being supplied to the system, sound pressure level measurements in octave-bands were taken at 2 foot intervals in both legs. This was a check for the acoustic equality of the two legs and for standing wave patterns. The only appreciable acoustic inequality was in the lowest octave band, 20 to 75 cps, where "live" leg measurements were approximately 2 decibels higher than those taken in the "dead" leg. Using a 40 cps pure tone, measurements were taken which showed a definite standing wave. However the length of a wedge with a cut-off frequency of 40 cps is about 10 feet. Thus a change in terminating wedge was considered impracticable. With no feasible method available for equalizing the low band readings, it was decided to accept the slight acoustic difference between the two legs and proceed to the calibration.

b. Method of Calibration

The windscreen was calibrated in the following manner: (1) Fan speed was adjusted by throttling the air inlet to the fan, (2) wind velocity was measured at the center of the "live" leg using an "Anemotherm", which is a heated wire anemometer, and (3) without touching the fan, sound pressure level measurements in octave-bands were then taken in each leg of the system. The same microphone was used in both legs. The authors then made the decision that if the "live" leg

reading exceeded the "dead" leg reading by 6 decibels or greater, the reading taken in the "live" leg would be considered the self-noise generated by the windscreen. Using this criteria curves of sound pressure level versus frequency in octave-bands with air velocity as a parameter were plotted. Because the sound power output of the fan is predominantly in the low bands, the 6 decibel criteria could not be met very satisfactorily in this region. Later in the investigation we determined that ducting covered with Fiberglas PF insulation in semi-rigid board form has very high attenuation characteristics in the low frequency bands. Utilizing a greater length of ducting with higher noise attenuation to reduce the fan noise as much as possible, it was possible to obtain more points in the lower frequency bands that could meet the 6 decibel criteria. The system ultimately used to obtain the data plotted in the RESULTS is that shown in Figure II.

2. Effect of Air Flow on Attenuation.

With the windscreen calibration available, a comparison of attenuation in still and moving air was next undertaken. The five lengths of 12" x 12" standard bare ducting were joined in line and supported at each joint with a saw horse. Again the standing wave problem was encountered at the lower frequencies. The same plywood exponential horn was used at the termination, however the effect of the 100 cycle wedge previously used was found to be insignificant. It was therefore removed. Three measurement runs were made: (1) with no

air flow, (2) with air flow at 1250 feet per minute, and (3) with air flow at 2200 feet per minute. The loudspeaker was used with the fan for the moving air runs in order to raise the noise level at least 10 decibels above the self-noise generated by the windscreen. With this difference the windscreen noise has negligible effect.

All attenuation measurements were taken in one-third octave-bands at three foot intervals down the duct. A Bruel and Kjaer third octave-band filter was used. The reason for using the narrower frequency band was to obtain a finer frequency breakdown over the audio spectrum. This is particularly desirable in the low frequencies where resonances produce very high attenuations over a narrow frequency band. The three foot measuring interval represents a compromise between continuous recording as the microphone is moved down the duct, and taking readings at only a few isolated points. The statistical aspect of the problem dictates that the closer the measuring interval, the more representative the results will be. However the time involved in taking a set of one-third octave-band readings is excessive, and the three foot interval was considered to be the shortest feasible distance to use.

From the plots of sound pressure level versus longitudinal distance for the three conditions under discussion, the authors concluded that the attenuation of sound in straight, unlined ventilation ducting is substantially independent of air flow.

A second phase of the investigation into the effect of air motion was conducted without the loudspeaker as a supplementary noise source The authors had hoped to take measurements in an installed system, but were unable to locate a long straight run with access for measuring. As an alternative, measurements were taken on the 12" x 24" duct covered with Fiberglas PF insulation in semi-rigid board form. The muffler was removed from the fan exhaust for the purpose of raising the noise level flowing into the duct from the fan. This was necessary in order to raise the noise level in the duct as high as possible above the noise generated by the windscreen. Readings were then taken under much the same conditions as a heating and ventilating engineer might encounter in an installed system. The readings were compared with those taken in still air using the loudspeaker as a noise source. The correlation of the results reaffirmed the conclusion that air flow has negligible effect on noise attenuation in ventilation ducting. The results indicated that it was unnecessary to use the fan in further attenuation measurements. Hence the white noise source-loudspeaker combination was used for all measurements taken in the next section.

3. Attenuation in Standard Ducting.

A comparison was made of attenuation with the 12" x 12" ducting supported at the joints versus support at the centers of the sections. The attenuation plots show that the results are essentially the same. The effect of support was also

investigated on the 12" x 24" duct, and again the effect of support was considered negligible.

In the measurements taken thus far, it was found that plots of sound pressure level versus distance from the noise source could be represented by a straight line, except for a few bands in the mid-frequency range. Considerable time and effort was spent in investigating this mid-frequency region, however the results were negative. Some measurements were taken using pure tones instead of white noise. The measurement interval was reduced to one inch for a 4000 cps pure tone signal. It was found that variations of 5 decibels within a two inch length were not uncommon. These rapid variations in sound pressure level are explained by the complex sound pressure distribution existing in a transverse section of the duct. The sound distribution changes continuously longitudinally down the duct, and in the mid-range frequencies the cross resonances and harmonics are strong enough to produce the complex variations noted.

The authors felt that if a sampling reading could be taken in a small area at the center of the duct rather than at a point, the radical variation in readings would be reduced. However a feasible method for such sampling was not available, and this theory could not be checked. Since the frequency bands causing the most trouble were all in the range of low attenuation, roughly .1 decibels per foot, it was decided that the problem was of insufficient importance to warrant further time.

The attenuation properties of the 12" x 12" duct with exterior thermal insulation were next investigated. Two conventional types of insulation were selected for testing. The first type used was Fiberglas Aerocor, with a density of 0.75 pounds per cubic foot and a thickness of 1 inch. Heavier Fiberglas PF semi-rigid 1 inch board of 6 pounds per cubic foot density was selected as the second insulation for testing. Glued clips were used to secure the insulation to the exterior of the duct.*

After taking the measurements with the thermal insulations on the duct, the Stic-Klips were removed. The final use of the 12" x 12" ducting was to coat it with a material for the sole purpose of increasing its mass. The object was to simulate the effect of increasing the gage of the duct metal without actually purchasing five more lengths of heavier, more expensive ducting. A 1/8 inch coating of plastic roofing cement was used to approximately double the mass of the duct. More specifically, the mass was increased from 28 pounds to 58 pounds.

Next measurements were conducted on five lengths of 12" x 24" standard ducting. The same procedures were used as have already been outlined for the 12" x 12" duct, with the exception that this size was not coated with roofing cement. As was previously mentioned, three lengths of 12" x 24" ducting covered with Fiberglas PF board were used to

*The Stic-Klips were kindly donated to the thesis project by Mr. Oliver Eckel. The insulation was donated by Owens-Corning Fiberglas Corporation.

attenuate fan noise in the re-calibration of the windscreen. The only special problem encountered during the investigation of the larger duct was that of terminating to reduce standing waves. Two of the 12" x 12" wedges previously mentioned were inserted side by side into the output end of the duct, and this set-up proved satisfactory.

We had originally intended to test an intermediate size of duct, probably 12" x 18". However a comparison of the two attenuation curves obtained from the 12" x 12" and 12" x 24" ducts indicated that essentially their attenuation properties are nearly the same, with the exception of the first few low frequency bands and the mid-band where transverse resonances occur. The authors felt that the testing of an intermediate duct size would not add enough to the results to warrant the financial and time expenditure.

Equipment data is listed in Appendix B.

APPENDIX B

EQUIPMENT DATA

(a) General Radio Co. Sound Level Meter
Type No. 1551-A, Serial No. 136.

(b) General Radio Co. Octave Band Analyzer
Type No. 1550-A, Serial No. 262.

(c) General Radio Co. Acoustic Calibrator
Type No. 308A-5.

(d) Bruel-Kjaer 1/3 Octave Filter
Model 1609, Serial No. 13308.

(e) Altec 21-BR-150 Condenser Microphone
Serial No. 150-6952.

(f) Altec Condenser Microphone Pre-Amplifier
Type 165A, Serial No. 11.

(g) Altec Power Supply
Type 526A, Serial No. 3.

(h) BBN Noise Source and Signal Generator.

(i) Anemotherm Air Meter
Serial No. 6033.

APPENDIX C

ORIGINAL DATA

TABLE II

CHECK of ACOUSTIC EQUALITY in LEGS of WINDSCREEN CALIBRATION SYSTEM

Live Leg:

Ft. from Y	SPL in Octave Bands 20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-10000
0	71.5	84	81.5	77	77.5	86 5	83.5	77.5
2	70	83.5	80.5	77	77.5	86	83.5	78.2
4	68.5	82	80.5	77	76.5	86	83	78
6	66.5	82.5	80.5	76.5	77 5	85.5	82.5	77
8	67.5	82.5	79.5	76.5	76.5	84.3	81.3	76
10	68.3	83.5	80	76	76 4	85.5	81.3	75.5
12	65.5	81.5	78.5	75.5	76.3	84.8	81.6	76
14	64.5	79.5	80.5	75.5	76	84.3	81.5	74.8

Dead Leg:

Ft. from Y	SPL in Octave Bands 20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-10000
0	69.3	81.5	81.5	77	77.6	85.6	81.3	76
2	67.5	81.5	81	76.5	76.5	84.5	82.8	76.3
4	65 5	82	80.3	77	76.3	85	80.8	76 8
6	65	80.4	80	76	76.3	84.8	81.3	75.8
8	64.5	79.8	78 5	76	75.8	83.5	79.4	73.5
10	64.5	79.5	78.5	76	76	83.4	81	75
12	64.5	79	77 5	75.4	76.2	83.3	80.5	74 5

TABLE III
ACOUSTIC TRANSPARENCY OF WINDSCREEN AND Y SCREEN

A. Windscreen measurements made outside of duct:

Octave Band	WHITE NOISE With Windscreen	WHITE NOISE Without Windscreen	PURE TONES Freq.	PURE TONES With Windscreen	PURE TONES Without Windscreen
20-75	59.5	60	50	80	80
75-150	68.5	68.5	106	80	80
150-300	75	75.5	212	79.5	79.8
300-600	76.5	76.5	425	80	79.8
600-1200	84	83.5	850	80.3	80
1200-2400	86.5	86.3	1700	80.9	80.9
2400-4800	82	82.7	3400	79.5	79.8
4800-10KC	81.5	81.2	6800	80.4	80.6

B. Y screen measurements made inside ducting with both legs acoustically terminated. Microphone 5 feet from the terminated end. White noise source. No windscreen on the microphone.

Octave Band	Dead Leg	Live Leg	Dead Leg	Live Leg
20-75	65.5	65	74.5	75
75-150	80	81	90	91.5
150-300	81.5	82.5	92	92.5
300-600	81	81.5	91.5	92.4
600-1200	83	83.5	93.5	94
1200-2400	85	85	95.2	95.5
2400-4800	80.3	81	90.5	91.2
4800-10KC	77	77.3	87	87

C. Windscreen and Y screen measurements made inside ducting with the microphone in the windscreen 5 feet from the terminated ends of the legs.

Octave Band	Dead Leg	Live Leg	Dead Leg	Live Leg
20-75	65.5	65	74.5	74.5
75-150	79.5	80.5	90	91
150-300	81.5	81.8	92	92.5
300-600	81	81	91.5	92
600-1200	82.7	83.3	93.5	94
1200-2400	84.5	85	95.5	95.5
2400-4800	79.5	80.4	90.5	90.5
4800-10KC	76	76	86	86

TABLE IV

VARIATION IN SOUND PRESSURE LEVEL AT 4000 CPS.

Duct size: 12" X 12"
Duct covering: None
Supported at: Joints
Measurements made every 1"

Condition I. Terminated with horn.

Condition II. Terminated with 100 cps wedges.

Position	Condition I	Condition II
1	80.5	80.5
2	82	79.3
3	82.4	81.8
4	82.7	81.6
5	86.3	83.3
6	79.2	80.1
7	82.8	82.3
8	85.4	84.2
9	83.8	85.1
10	89.1	88
11	88.5	86.5
12	89.8	86.9
13	85.5	84.5
14	86.6	84.9
15	81.8	80.1
16	79.5	80.1
17	85.1	83.2
18	85.7	86.1
19	92.1	90.7
20	90.4	90
21	92.8	89.8
22	88	87.4
23	88.7	86.5
24	86.1	81.3
25	84.4	81
26	86.5	84.5

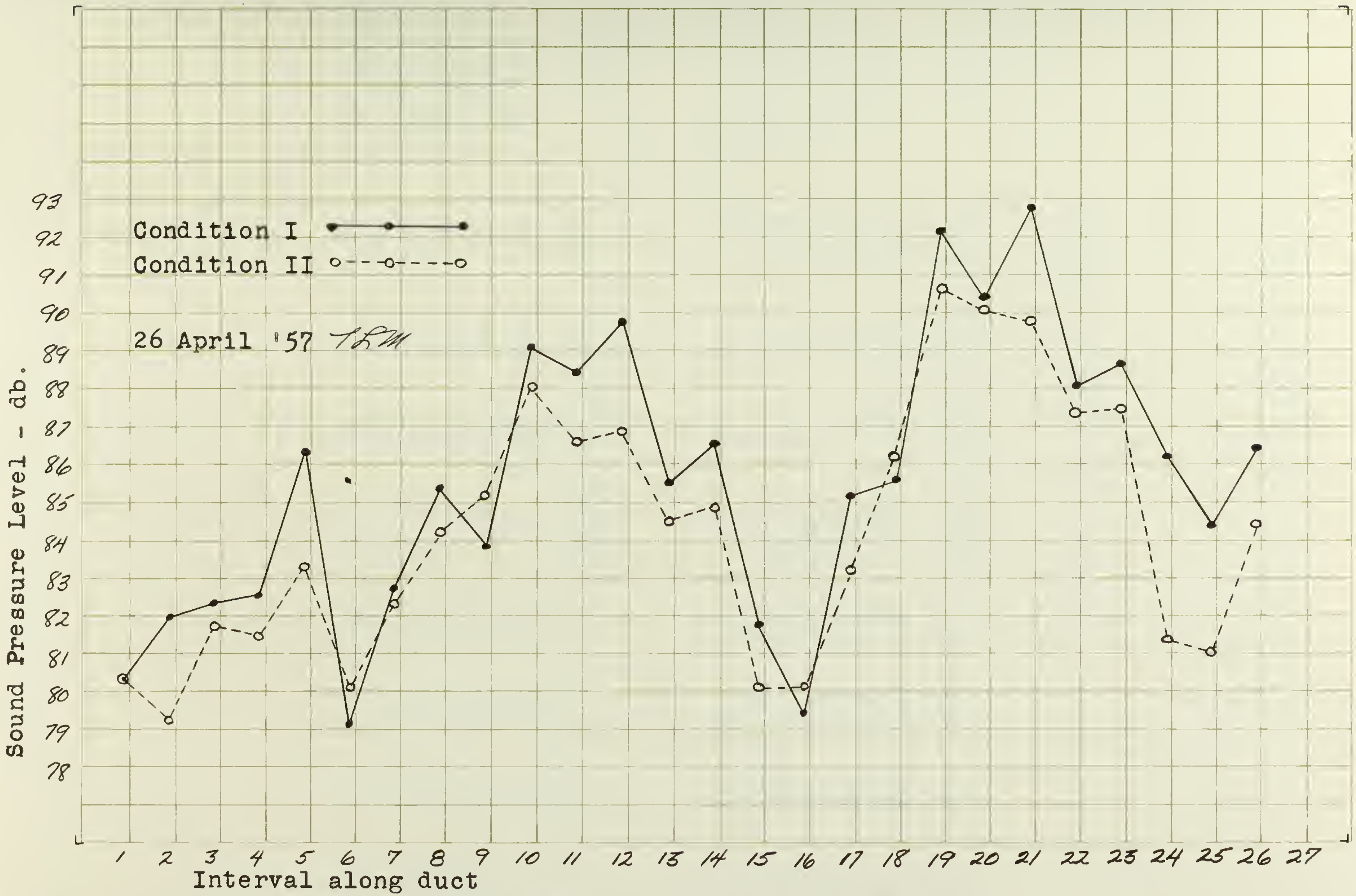

Figure XV. 4000 ~ SPL at 1" intervals within 12" X 12" bare duct.

TABLE V
PRELIMINARY WINDSCREEN CALIBRATION DATA

MEASURED SOUND PRESSURE LEVELS

Live Leg:

Octave Band	Air Velocity (Ft/min) 3800	3500	3100	2650	2400	2050	1650	1100
20-75	104	104.5	103	97.5	95.5	86	83	78
75-150	96	90.5	88.5	82	80	72.5	64.5	60
150-300	85	80	78	71.5	69.5	62	57	51.5
300-600	76	72	70	63.5	61.5	55	50	45
600-1200	78	74	72	69.5	66	62	57	47
1200-2400	77	74	72	67.5	65.5	59.5	50	43.5
2400-4800	76	72	70	62	59	49.5	44.5	42.5
4800-10000	71	67.5	66	60	60	48	47	52

Dead Leg:

Octave Band	Air Velocity (Ft/min) 3800	3500	3100	2650	2400	2050	1650	1100
20-75	94	93.5	93.5	92	91	85	82	75
75-150	94	89	85.5	76	74	66	61	58
150-300	81	75	72	67	64	56	51.5	48
300-600	71	66	63	57	56	48.5	43	38.5
600-1200	62.5	58	57	52	51.5	41.5	39	38
1200-2400	60	57	56	53.5	53.5	42.5	41.5	40.5
2400-4800	59.5	57.5	56	55	55	43.5	43	42
4800-10000	62	61	60	59.5	59.5	47	47	44.5

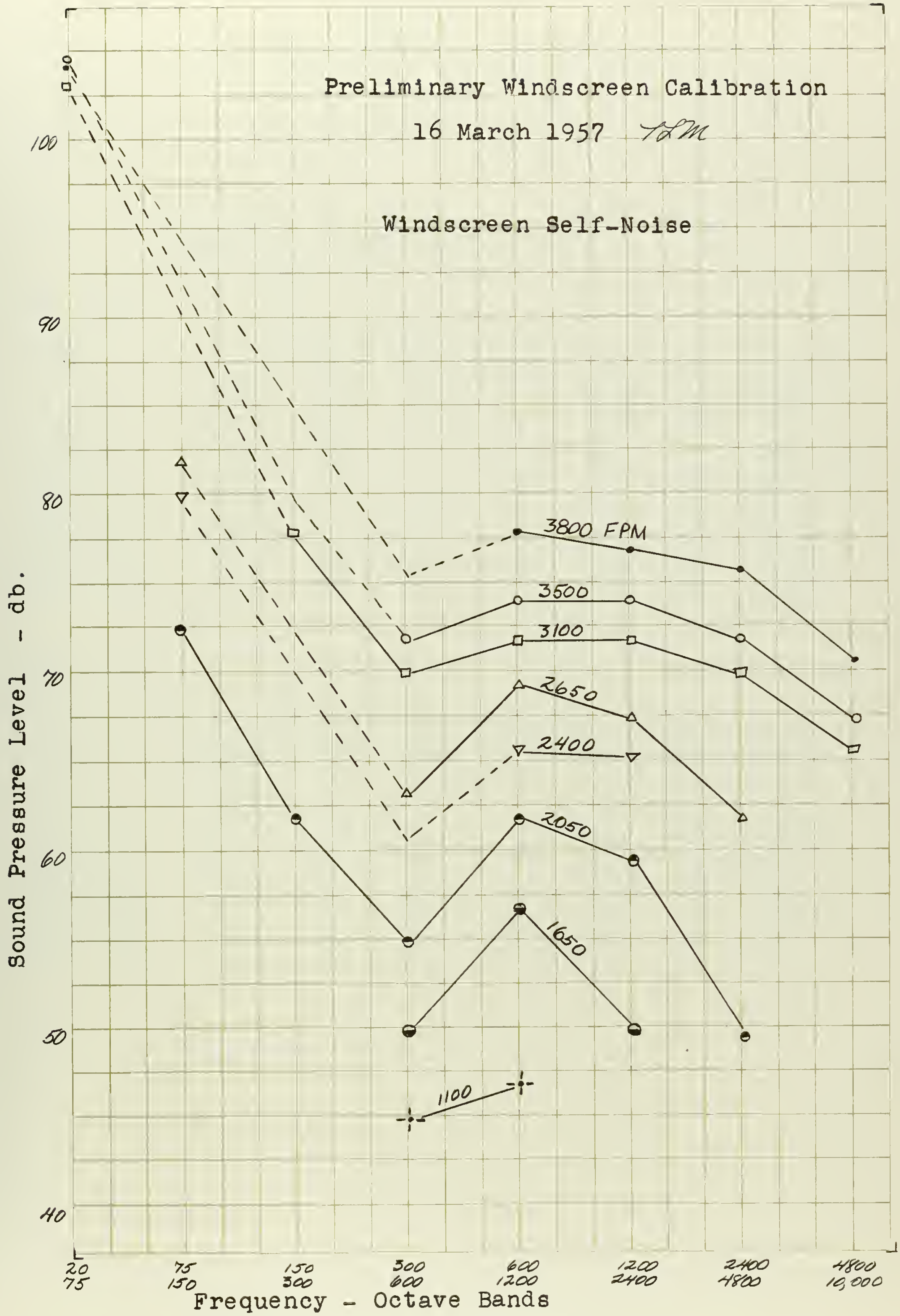

Figure XVII. Preliminary Windscreen Calibration

TABLE VI
FINAL WINDSCREEN CALIBRATION DATA

MEASURED SOUND PRESSURE LEVELS

Live Leg:

Octave Band	Air Velocity (Ft/min) 4300	3200	2800	2500	2000	1600	1100
20-75	109	103	100.5	95	86.5	82	79
75-150	98	88.5	86	81	72	62.5	54
150-300	86	81	75	70	60	53	50
300-600	78.5	70	66.5	63.5	57	51.5	49
600-1200	78.5	72	68	66	60.5	55	41.5
1200-2400	77.5	71.5	68	65.5	60.5	50	35.5
2400-4800	75	68.5	64	60	49	39	26.5
4800-10000	70.5	62	55	49	39.5	38	28.5

Dead Leg:

Octave Band	Air Velocity (Ft/min) 4300	3200	2800	2500	2000	1600	1100
20-75	99.5	96	92.5	87	76 5	75.5	76
75-150	96	92.5	85	74.5	70.5	56	49.5
150-300	81	71.5	67	61	54	48.5	46
300-600	65	57.5	53	47	45.5	44.5	44
600-1200	57	51	49.5	42.5	36	27.5	20$^-$
1200-2400	57.5	53	51	44	37	27	20$^-$
2400-4800	57	52	51	44	32	27	20$^-$
4800-10000	60	52.5	51.5	43.5	31	27.5	20$^-$

TABLE VII
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 12"
Duct covering: None
Supported at: Center of panels
Termination: Horn approximation-no wedge

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	64	71	84	90	92.5	93	90.5	91	90.5
6	58	61	73	85.5	92	93	89.5	90	90.5
9	57	58.5	70	83	90	92	86	89	89
12	54.5	55	63	80	89	91.5	85.5	88	89
15	55	54.5	61	76	88.5	90	85.5	87.5	89
18	52	53.5	60	74	88.5	89.5	84	86	88
21	50	52	59.5	72	87	90	85	85.5	88
24	54	54	65.5	70	84	88	83	83.5	87.5
27	48	50.5	61	69	83.5	88	79.5	83.5	87
30	50	49	56.5	68.5	84	88	82	83.5	87.5
33	47	48.5	56	68	84	86.5	82	81.5	86
36	45	48	59	66	81	87	79	79.5	87

	320	400	500	640	800	1000	1250	1600	2000
3	89	87	82.5	85.5	88.5	93.5	98.5	97	97.5
6	89	86	82.5	85	89	91.5	96.5	97	97.5
9	89	85.5	82	84.5	88	91	96	96.5	96.5
12	88	86.5	82	85	88	90.5	95.5	96.5	96
15	88.5	86.5	82	84.5	88	91	95.5	95.5	95.5
18	88	85.5	81	84.5	87.5	90.5	94	96	95.5
21	88	85	80.5	84.5	87	90.5	93.5	95.5	95
24	87.5	84.5	80	84.5	87	90.5	92.5	95	94.5
27	87.5	85	80.5	84.5	87	90	92.5	94.5	94.5
30	87.5	84.5	80	84	87	89.5	92	94	93.5
33	87	84	79.5	83.5	86.5	89	91	93	93
36	85	82	78.5	82.5	86	89	90.5	93	92.5

	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	99	89.5	80	83	89.5	86.5	81	75.5	65.5
6	96	91.5	91.5	84	86.5	82.5	78.5	74	64.5
9	95.5	92	82	87.5	91	83.5	76.5	71	62
12	96.5	90	89	81.5	90.5	86	77.5	71	61
15	95.5	91	85	84	86	82.5	78	72	60
18	95.5	90.5	87.5	85	85.5	79	76.5	71	60
21	95	89	85.5	82	89	80.5	74.5	70.5	59.5
24	94.5	90	86.5	83.5	87.5	83	73	69	57.5
27	95	88	84.5	82	84	81	72.5	65.5	58
30	94.5	89	85.5	81.5	85.5	78	72.5	65	57.5
33	94	88	84	81.5	86.5	76	74	62	56
36	93	87.5	84	81	85	80	71	63	54

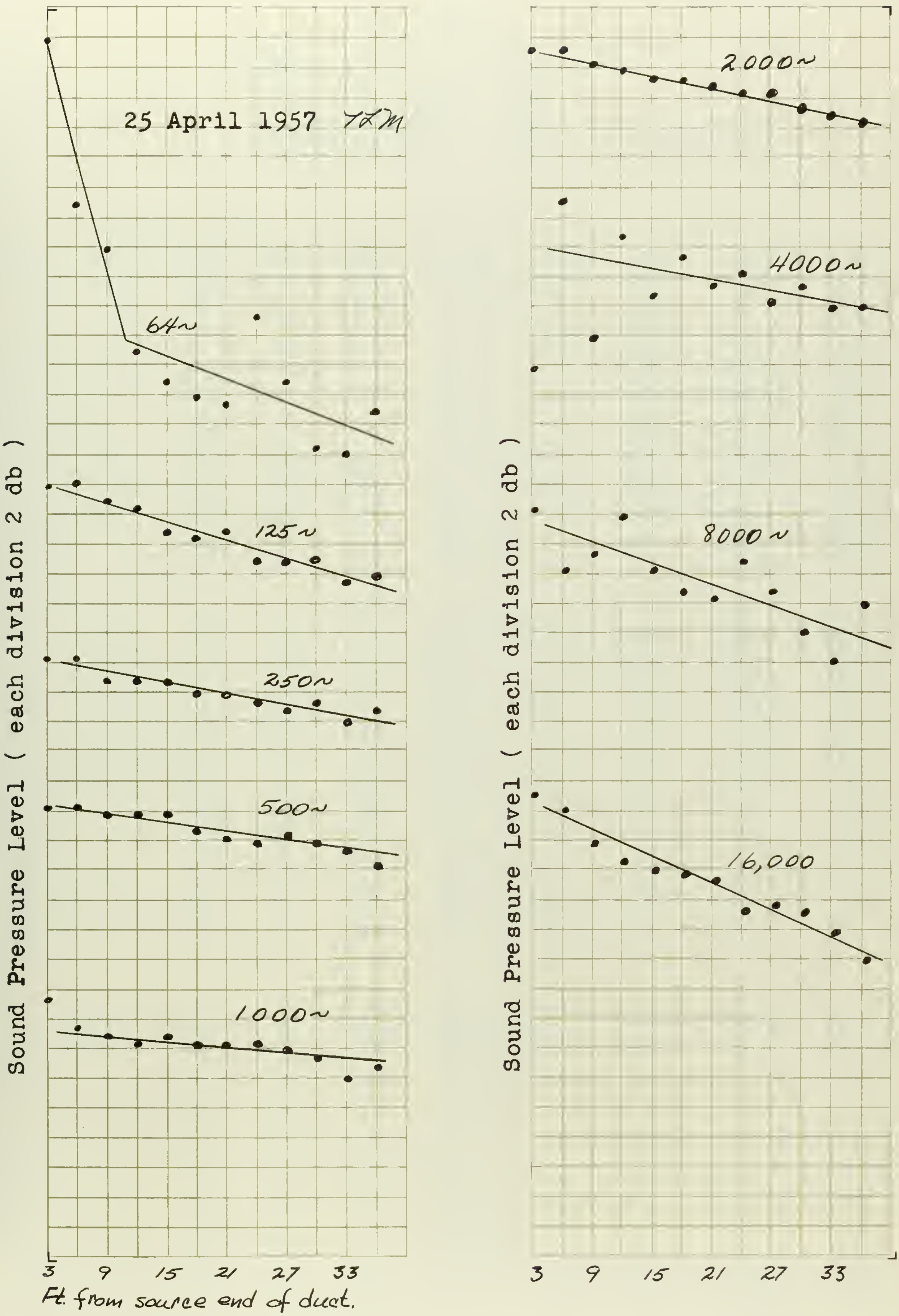

Figure XVIII. Measured SPL in bare 12" X 12" (center support)

TABLE VIII
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 12"
Duct covering: None
Supported at: Joints
Termination: Horn approximation

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	63.5	66.5	81.5	86.5	92.5	93	90	90	89.5
6	62	62.5	73	83.5	91	92	89.5	90	90
9	58	58	66	80	90	91.5	87	88	89.5
12	51.5	54	62.5	78	90	91	86	88	89
15	56.5	55.5	64.5	74	88	91	85.5	86.5	88.5
18	51	52.5	60	73.5	89.5	90	85.5	85.5	88
21	51	51	57	72	87	91	83.5	86	88
24	53.5	51.5	59.5	71	84.5	89	83	84.5	87.5
27	49	50	57.5	69	85.5	88	81.5	84	87.5
30	51	50.5	57	70	84	90	82.5	84	87.5
33	48	49	55.5	68	82.5	86	82	82	86.5
36	46.5	47.5	54.5	66.5	83	89	81	81.5	88.5

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	89.5	87	82.5	85.5	89	93	99	97	97
6	89.5	87	82.5	85	89	92.5	97	98	97.5
9	89	87	81.5	84.5	88	91	96.5	96.5	96.5
12	88.5	86.5	82	84.5	88	91.5	96	96.5	96
15	88.5	86.5	81.5	84.5	88.5	92	96	96	96
18	89	85	81	84.5	88	91	95	96	95.5
21	88	85.5	81.5	84	87	90.5	94	96	95
24	88	85.5	80	84.5	87.5	90	93.5	95.5	94.5
27	88	84.5	80.5	84	86	90	93.5	95.5	94.5
30	87.5	84	80	84	86.5	90	92.5	95	94
33	87.5	83.5	79	84	86	89.5	92	94.5	94
36	86	83.5	79	84	86.5	89.5	92	94.5	93.5

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	100	91.5	83	82.5	90	84	79	75.5	65.5
6	97	90.5	91	85.5	87.5	82	78	74	65
9	95.5	92.5	82.5	87	90.5	85	77	71.5	61.5
12	96.5	90	89.5	82	89.5	86	76.5	70	62
15	95.5	91	84	84.5	85	82.5	75.5	71.5	61
18	95.5	91	87.5	84.5	86	79	76.5	72	60.5
21	95	89	85	81.5	90	80.5	75.5	71	59
24	94.5	90	86.5	84	87.5	83.5	72	68.5	58
27	95	88.5	84.5	82.5	84.5	81.5	72	66	57
30	94.5	89.5	86	82	86.5	78	72.5	65.5	57.5
33	94	88.5	84	81.5	87	76	73	63.5	56
36	94	88	84.5	81	85	80	71	63.5	54.5

TABLE IX
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 12"
Duct covering: None
Supported at: Joints
Termination: Fan - Muffler combination

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	60	63.5	80	81	85.5	86	85	84.5	84
6	53.5	53.5	67	76.5	84.5	86.5	83	85	84.5
9	54	52.5	67	75	82.5	85.5	80.5	82.5	83.5
12	50	49	61	72	82	84	80	82.5	83
15	53	47.5	58.5	69.5	80	84	78	81.5	83
18	47	45	55	67.5	80	83	77.5	80.5	82
21	45.5	42	52	65	79.5	83	76	80	82
24	48	43.5	55.5	63	76.5	83	75	79.5	81
27	42	41	48	61.5	75.5	81.5	74.5	77	81
30	44.5	43	56.5	60	76.5	80.5	77	78	81.5
33	44	41	54	60	72.5	82	73	77	80
36	43	38	51	58	74.5	76.5	69	78.5	79.5

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	82	82	76	80	83	87.5	92.5	92.5	93
6	83	82	76.5	79.5	83.5	86	92	92.5	93
9	82.5	81.5	76	79	83	85	90.5	92	91
12	82	80.5	75.5	79	82.5	85	90	91	90.5
15	82.5	80.5	76	79	82.5	85	89	91.5	90
18	81.5	79.5	75	78.5	82.5	84.5	88.5	91	89.5
21	82	79.5	75	78	82	85	88.5	90.5	89.5
24	81.5	79	74	78	81	84.5	88	89.5	88.5
27	81.5	78.5	74	77.5	81	84	87	89.5	88
30	81.5	79	73.5	78	81	83.5	86.5	90	88
33	81	79	73	78	81	83.5	87	89	87.5
36	81	79	74	77.5	80	84	86.5	90	87.5

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	94	83.5	77.5	80.5	85	83	77	69	62.5
6	91	87	85.5	81	82.5	77.5	77	69	61.5
9	91.5	87	78.5	83.5	86	79	73.5	66	59
12	92	85	83.5	79	87	81	74.5	65	58
15	91	87	81	78.5	81.5	78	75.5	65	57
18	90.5	84.5	81	80	81	75	72.5	63	57.5
21	91	85	81	77.5	84	75.5	71	65	56
24	90.5	84.5	80.5	78	83	77	69	63	57.5
27	89.5	83	80	77	79	75	67.5	60	55.5
30	89.5	84.5	79.5	76	79.5	73.5	67.5	60	53.5
33	90	83.5	79	76.5	82	72.5	69	58	52
36	89	84	79.5	75.5	80.5	74	66.5	58.5	51

TABLE X
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 12"
Duct covering: None
Supported at: Joints
Termination: Exponential horn-no wedge
Air Flow: 2200 FPM

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	82.5	73	80.5	87.5	94.5	96.5	91.5	92.5	90.5
6	78.5	71	77.5	85.5	96.5	96	89	92.5	90.5
9	79	68	74.5	82.5	95	96	89.5	92	90
12	78.5	67	73.5	82.5	95.5	94.5	88.5	90.5	89.5
15	74.5	66.5	72	79	94.5	95.5	86.5	90.5	89.5
18	77.5	67	74	79.5	91.5	94	86	89	89.5
21	74	64.5	71	77.5	90.5	92.5	85.5	87	88
24	74	65	70	76	91.5	94	85.5	88	89.5
27	76.5	66	73	75	89.5	93.5	84	86.5	87
30	73	65.5	70.5	76	90	93	84.5	87.5	88

	320	400	500	640	800	1000	1250	1600	2000
3	88.5	87.5	86	81.5	87.5	90.5	90.5	96.5	101
6	88.5	87	85.5	81	89.5	90.5	89.5	96	100.5
9	88	87	85.5	82	88.5	90	90.5	96	100.5
12	87.5	86.5	85	81	88	89	88.5	94.5	98
15	87.5	85.5	84	81	87	89	88.5	94	100.5
18	86.5	86	84	81.5	88.5	88.5	86.5	93.5	98.5
21	86	84.5	83.5	80.5	87.5	88.5	88	93	97
24	86.5	85.5	83.5	80.5	86.5	88.5	90	92.5	99
27	86	84.5	83.5	81	87	89	90	92.5	96.5
30	85.5	84	83	80.5	87	88.5	91	92.5	97

	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	102.5	96	91	89	93.5	89	83	77	68.5
6	99.5	94.5	90.5	87.5	91	86.5	83	76	66
9	101.5	94.5	91	87.5	91.5	86.5	81	74.5	65.5
12	100.5	92.5	88	86	90.5	83.5	78	71	64
15	99.5	92	86.5	85.5	89.5	83	78.5	70.5	62.5
18	100	91.5	86.5	84	88	83	77	69	61.5
21	98.5	91.5	86.5	83	86	80.5	73.5	67.5	60
24	98	91	86	83.5	86.5	80.5	73.5	67	59
27	97	89.5	86	82.5	86	79.5	72	66	56.5
30	97.5	90	84.5	82	85.5	79.5	72	65.5	56

TABLE XI

MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 12"
Duct covering: None
Supported at: Joints
Termination: Exponential horn-no wedge
Air Flow: None

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	64.5	63	73.5	86.5	95.5	96.5	92.5	93	90
6	58	61.5	70.5	81.5	96	95.5	88.5	92.5	91
9	62	59.5	68.5	83.5	94	95.5	89	92	89.5
12	61.5	58	65.5	81	94.5	94.5	88	90	90.5
15	60.5	57.5	65.5	78.5	94.5	95.5	87	89.5	89
18	61	58	68	77	92	94.5	87	88.5	89.5
21	53	54	63	77	91.5	94	86	88	89
24	53	55.5	63.5	75	91.5	94	86.5	88.5	88.5
27	56	53	62	74	89.5	92.5	86	86.5	88.5
30	-	-	59.5	74.5	89	93	84	87.5	87

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	88.5	88.5	86	81.5	88	89.5	90	96.5	100.5
6	87.5	86.5	85.5	81.5	89	90	88.5	95	99.5
9	87.5	86.5	85.5	82	88	88.5	89	95.5	99.5
12	87.5	86.5	84.5	80.5	88.5	89	89	94.5	97.5
15	87.5	86.5	84	81	87.5	89	89	94.5	99
18	87.5	86	84	81.5	89	89	87	94	98.5
21	86.5	85	84	81	87.5	88	88.5	93.5	96
24	86	85	84	81	87	88.5	90	93	98.5
27	87	84.5	83	80	87.5	88	89.5	92.5	96.5
30	86.5	84.5	83	80	86.5	88.5	90.5	92	96

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	101.5	94.5	89	88	92	87	82.5	76	72
6	99.5	94	89.5	87	91	86	81	74.5	65
9	99.5	93.5	90	86.5	90	84.5	80.5	74.5	67.5
12	99.5	92.5	87	86	90.5	83	77	70.5	64
15	98.5	92	86	84.5	87.5	83	77	69.5	62.5
18	99.5	91.5	86.5	83	87.5	82	76.5	68	61.5
21	98	90.5	86	82.5	85.5	80	73	67.5	59.5
24	98	90.5	86	83	86	79.5	72	67	59
27	96.5	89	84	81.5	84.5	78.5	70.5	66	57.5
30	96.5	89	83	81.5	84	78.5	71	65	56

TABLE XII
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 12"
Duct covering: Aerocor
Supported at: Center of panels
Termination: Horn Approximation

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	68.5	78	86.5	90.5	94	94.5	93	92.5	92.5
6	60	67.5	78	86.5	93	94	91	92.5	91.5
9	57.5	63	70	83	91.5	92.5	88	89.5	91.5
12	54.5	58.5	66	81	90.5	93	88	89	90
15	56	58	63	78	90	91.5	88	87.5	90
18	52	55.5	61.5	74	89.5	91.5	86	87	88
21	50.5	54.5	58.5	73	87.5	90	83	86	89
24	51	55	60	68	85	87.5	82	85	88
27	49	52	57.5	68	84.5	88.5	82	82.5	87
30	47.5	51.5	55	67	83	87	81.5	82.5	86.5
33	46.5	51	57	64	82	86.5	81	80.5	86.5
36	47.5	53	58	62	80	86	78.5	82	86

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	91	89	85	87	91.5	96	101	100	101.5
6	90.5	89	84	86	91	93.5	99.5	99.5	100.5
9	90.5	88.5	83	86.5	91	93.5	98.5	99.5	99
12	90.5	88	82.5	86.5	91	93.5	98.5	99	98.5
15	89.5	87	83	86.5	89.5	93	96	98.5	98
18	88.5	86	82.5	86	89	92.5	96	97.5	98
21	88.5	85.5	81.5	86	88.5	92.5	95	97	97
24	87	84.5	81	85	88.5	92	93.5	96	96.5
27	88	85	80.5	85.5	89	92	92.5	96	96
30	87.5	84.5	80.5	85.5	87.5	92	93.5	94.5	95
33	87	84.5	79.5	85	88	91.5	93	94.5	95
36	86.5	84	79.5	85	87	92.5	92	94	94

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	102	91.5	86	89	92.5	91	86	79	69.5
6	98	95	94	88.5	90	86	86.5	80	69.5
9	99	94.5	86.5	90.5	94.5	89	83.5	77.5	66.5
12	99.5	93	91.5	86	94	89.5	82.5	74	67
15	98.5	94.5	88	86	89	87	85	77.5	66 5
18	98	92.5	89.5	87	89	84.5	80.5	76	64
21	97	92.5	88	84	92	84	78.5	75.5	62
24	97.5	92.5	88	85	90.5	85.5	78	72.5	61.5
27	97	90.5	88	84.5	86 5	84	79	71.5	60.5
30	96.5	92	87	83.5	87	81.5	76	68.5	59.5
33	96.5	89.5	86.5	83.5	90.5	81	76.5	66.5	58
36	96	91	86	82.5	87	82	74	66	55.5

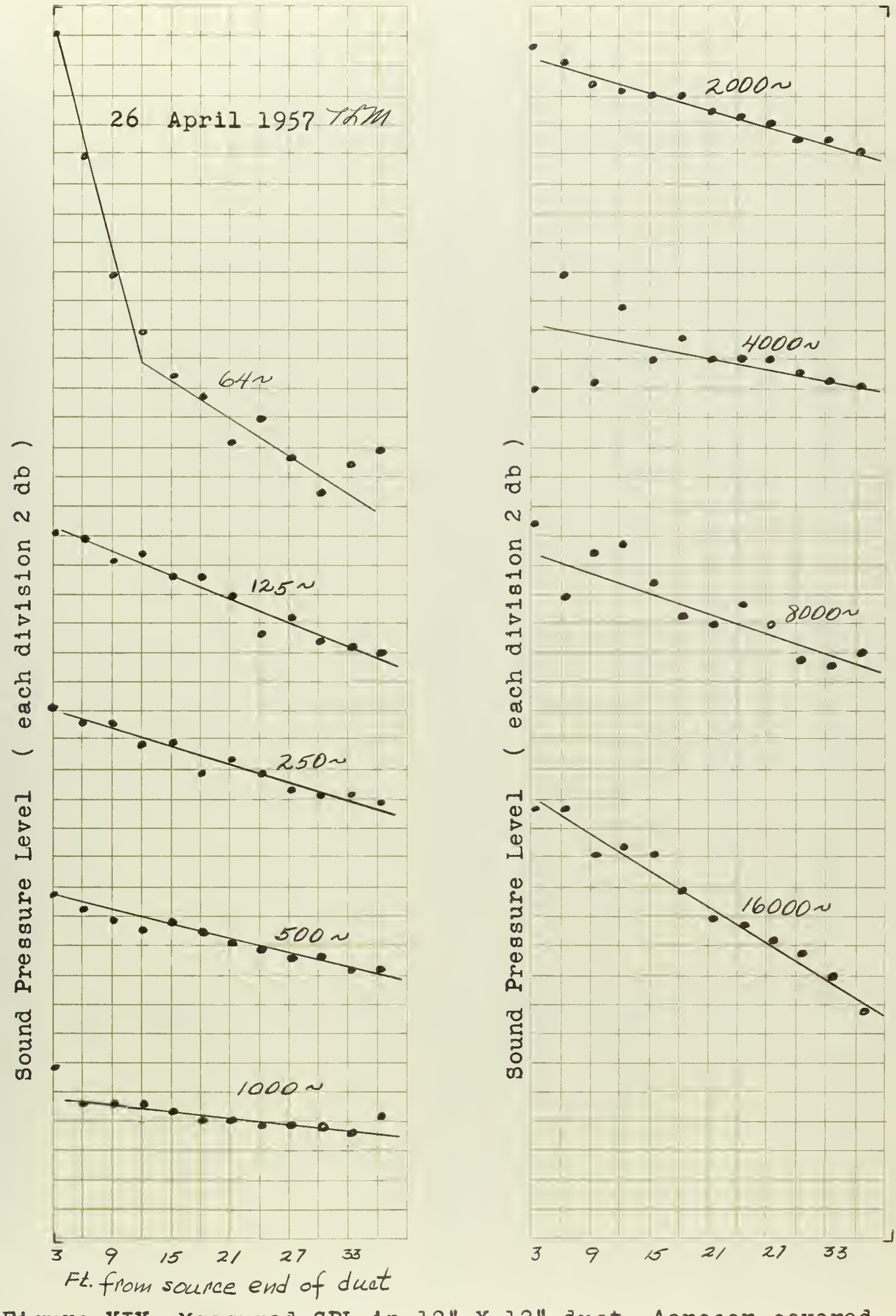

Figure XIX. Measured SPL in 12" X 12" duct, Aerocor covered.

TABLE XIII

MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 12"
Duct covering: Semi-rigid P.F. board
Supported at: Center of panels
Termination: Horn Approximation

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	70.5	78	88	86	90	90.5	91	88	88.5
6	67	71.5	82	87	85.5	89	89.5	86	88
9	63.5	67	74.5	80	84	86	87	85	86.5
12	61	60	68	76	83.5	85.5	86.5	83.5	86
15	60	57.5	64	72	80.5	83.5	84.5	81.5	84
18	59	55.5	61	70	76.5	82	83.5	79.5	83
21	57	53.5	59.5	67	75.5	80	82	78.5	82.5
24	54	52	57	67	71.5	78	82	76	81.5
27	53	50	53.5	65	71.5	76	79	74.5	80
30	52	46	52	62	67	75.5	77	72.5	79
33	49.5	46	51	63	65	73.5	76	71	77
36	49	44	50	61	63.5	71.5	74.5	68	76

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	88.5	87	82	85	89	92.5	98.5	98	98.5
6	88	86	81.5	85	89	91	97	97.5	98.5
9	87	86	80.5	84.5	88.5	91.5	96.5	97.5	97
12	86	85.5	80	84.5	88.5	91	95.5	96.5	96.5
15	85.5	84.5	79	84	88	91	94	96	96
18	84	83.5	77.5	83.5	87.5	90.5	93.5	96	95.5
21	84.5	83	77	84	87.5	90.5	92	95	95.5
24	83.5	82.5	76	83	87.5	90	91	94.5	94.5
27	82	81	75.5	83	86.5	90	90	94	94
30	81	80.5	74.5	82.5	86.5	89.5	90	93.5	93.5
33	80	79	74	82	86	89	89	92.5	92
36	79.5	79	73	82	86	89	89	92	92

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	100	89.5	82.5	86	91	90	85.5	77.5	73.5
6	96	92.5	92	86.5	87.5	85	87	77.5	73.5
9	97	93	84	88.5	93.5	87	85	75	69.5
12	97	90.5	90	84	92.5	89.5	84.5	77	71
15	96.5	92.5	86	85	87	86	84.5	75	70.5
18	96	91	87.5	86	87.5	83.5	81.5	76	68.5
21	96	90.5	86.5	83	91.5	84.5	80.5	75	67
24	96	91	86	84.5	89	86.5	79	72	66.5
27	96	89	86	83	86	83.5	79.5	71	64.5
30	94.5	90	85.5	82.5	87	81.5	78	70	63.5
33	94.5	88	84.5	83	88.5	81	77	68	62
36	94.5	89	84.5	81	85.5	83	75	68	60

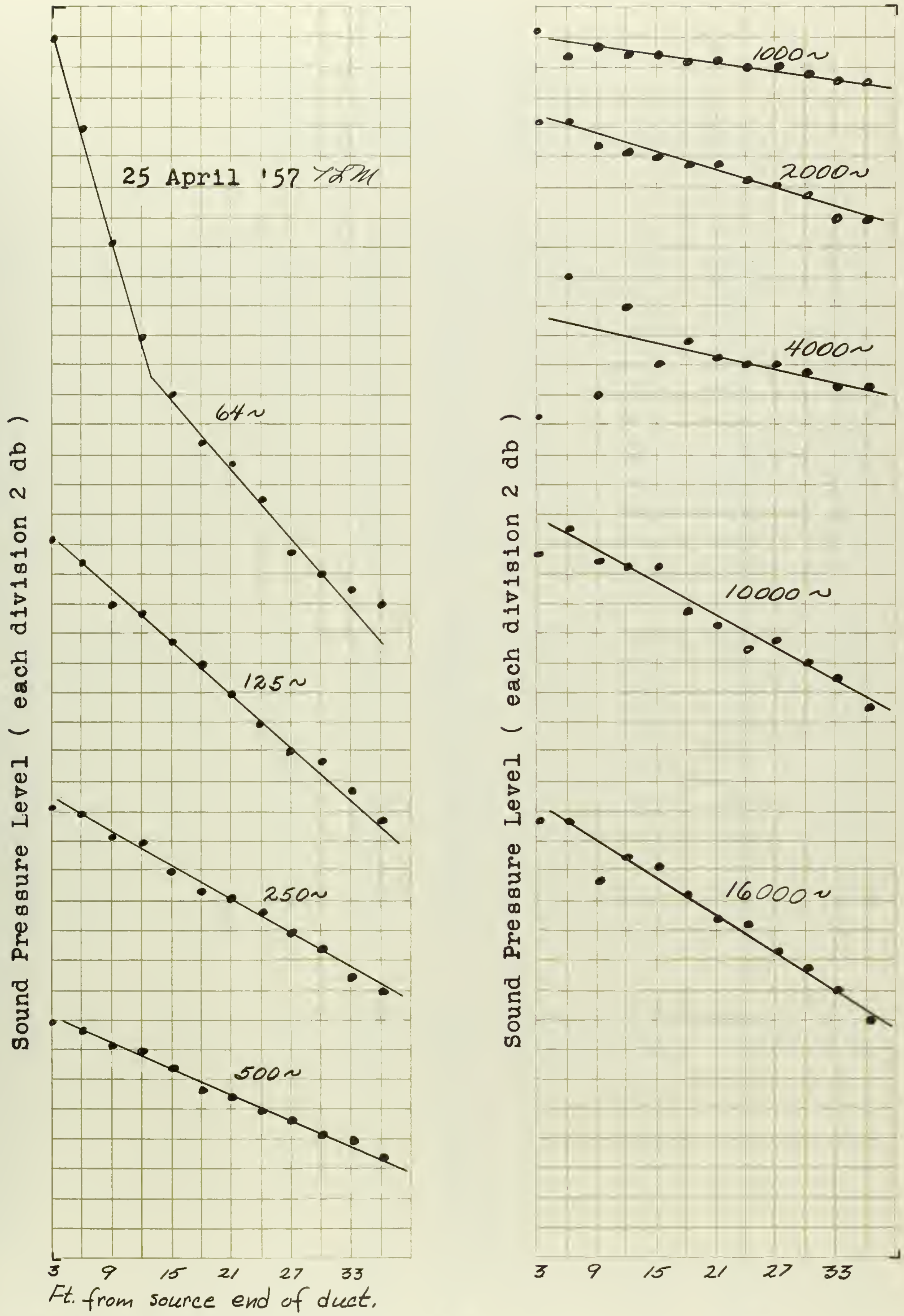

Figure XX. Measured SPL in 12" X 12" duct, P.F. board covered.

TABLE XIV
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 12"
Duct covering: Roofing cement
Supported at: Joints
Termination: Horn Approximation

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	71.5	83	92	90	90.5	91.5	91	92	91.5
6	67	79	88	89	91.5	90	90	91	91.5
9	64	75	84.5	85	90	88	90	92	90.5
12	62	73	83.5	86	88	87	89	91	90
15	58.5	70	81.5	86	90	83	89	91	91.5
18	56.5	67	80	84	87	83	87	91	90
21	56	66.5	78	87	88	81	86	90.5	90
24	54.5	64	76	83.5	86.5	80	87	89.5	89
27	53	62	74	86	85	76	85	90	89
30	52	60	72.5	85	85	76.5	86.5	89	89
33	50.5	57	70	80	85.5	73.5	84	89	89.5
36	52	60	72.5	83.5	80	73.5	83.5	89	87

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	89.5	89	84	86	90	93	99	98.5	100.5
6	90	89	84	86	90	93	99	98.5	99
9	89	88	83.5	85.5	89.5	92.5	98	98	97.5
12	88.5	88	83.5	85	90	93	99	98.5	97.5
15	87	88	83.5	85	90	92	98.5	98	97.5
18	87.5	88	84	85.5	89.5	92	97	97	96.5
21	87	87	83	84	89.5	92	96.5	96.5	96
24	87	87	83	84.5	89	91.5	97	96	96.5
27	85.5	86	83.5	84	89	91.5	96	95.5	95.5
30	85	86	83	83.5	88.5	91	95.5	95	95
33	84.5	85.5	82	84	89	89.5	94	94.5	95
36	85	85.5	82	83	88	90	94	94.5	94

Ft.	2500	V3200	4000	5000	6400	8000	10000	12500	16000
3	101	92	84	85.5	92	91.5	85.5	79.5	72.5
6	95.5	96	91.5	84	88	84.5	84.5	79.5	72
9	98.5	92	87.5	89	91	85	83	77	70.5
12	98	93.5	88.5	85 5	94	89.5	83.5	76	68
15	97.5	94	89.5	85	89	88	83.5	73.5	67
18	97	91.5	86.5	86	86	83	82.5	73.5	66
21	96.5	92.5	88	83	89.5	82	79	73.5	64.5
24	97.5	91.5	86	83.5	90.5	83.5	77.5	73 5	64.5
27	95.5	90	87	84	87.5	84 5	76	71	64.5
30	95.5	91	86	82.5	85.5	82	77	68	62
33	95	89.5	85.5	82.5	88.5	81	76	68	60.5
36	95	89.5	84	81	87	80	74	66	58.5

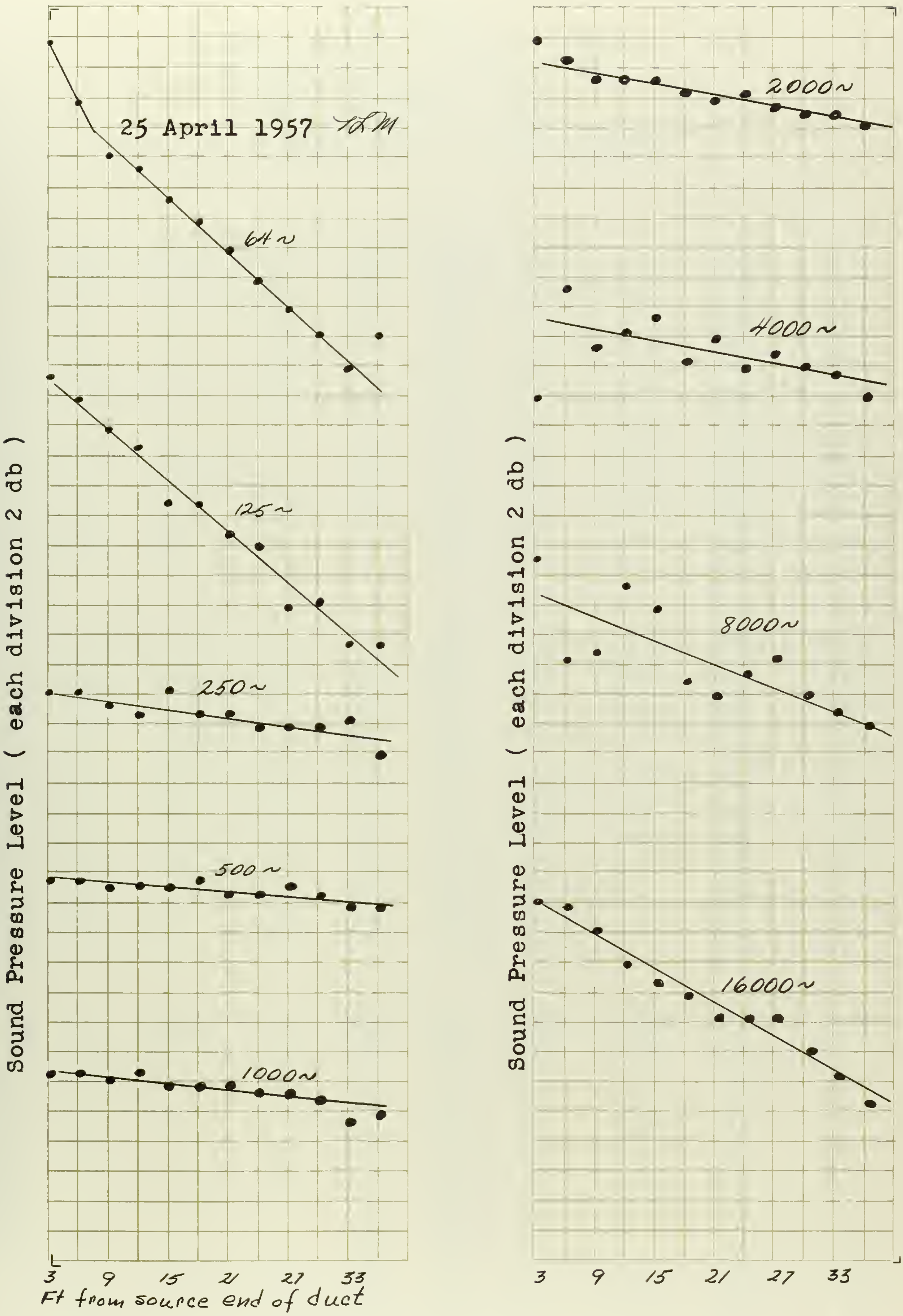

Figure XXI. Measured SPL in 12" X 12" duct with added mass.

TABLE XV
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 24"
Duct covering: None
Supported at: Center of panels
Termination: 100 wedges

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	67	76	84	90	92.5	92.5	92	90	88
6	64	75	83.5	87	92	93	92	89.5	87
9	58	66	76	87	90	92.5	91	88	88.5
12	57.5	66	75.5	83	91	91	90	87	87
15	53.5	59	70	82	87.5	90.5	91	87.5	87
18	53	61	68	81.5	86	88.5	90.5	86	86
21	52	59	67	80	85.5	89	89	86.5	85.5
24	53	61.5	70	76.5	84	88	87.5	85	86
27	51	59	66.5	75	84	86	86.5	85	85.5
30	50	55	63	75.5	83.5	88	88	84	84.5
33	50	54	62	73	82	86	88	83.5	84.5
36	49	53	61.5	72	78.5	83.5	86	83	83.5

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	88	87	83.5	95	94	98	100	97	100
6	87	86.5	84	93.5	94	97	98	100	93.5
9	88	86	83	92	96	93	98.5	98	99.5
12	87	86.5	82	93	94	95.5	97	97.5	99.5
15	88	86.5	82.5	93	94.5	94.5	97 5	96.5	96.5
18	87	86	82	92	94	93.5	97	97	96
21	88	86	82	91	94	94	96	96.5	96
24	87	85.5	81.5	91	93.5	93.5	96 5	96	96.5
27	87	85.5	81	90.5	93.5	94	96	96	97
30	86	85	81	90	93.5	93.5	96	95.5	96.5
33	86	85	80.5	89	92.5	92.5	95	95	95
36	85.5	85	80	89	92.5	92.5	95	95	95

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	99	87.5	85	85	91	83	80.5	74	68
6	92.5	93	90	85	85.5	82	79	73	64
9	93.5	86.5	85.5	87	90	81	78	72.5	65
12	98.5	87	80.5	82.5	90	83	76.5	73	63
15	98	92	81.5	80	85.5	81	76.5	72	62.5
18	96	91.5	87	81	83.5	80	76	72	61
21	93.5	92.5	86	80	82	79	75.5	72	60
24	94	90	88	83	82	78.5	73.5	70.5	60
27	96.5	87	87	82.5	82	76	73	68	59
30	96	87.5	86	83	84	76.5	74	67.5	58
33	95	87.5	83	82.5	87.5	77	71.5	65 5	57
36	94	90	81.5	81.5	85.5	78	71	66	56

TABLE XVI
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 24"
Duct covering: None
Supported at: Joints
Termination: 100 wedges

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	69	75	84.5	91	91.5	92	92	90	88.5
6	64	70	81.5	89	92.5	93	91	89	88
9	60	67.5	77	86	90	92.5	90.5	88	88
12	56.5	66	75.5	83.5	90.5	91.5	91	88.5	87
15	55.5	62	72.5	81	88.5	90.5	91	87	87
18	53	59	68	79.5	86.5	89.5	90.5	86.5	86.5
21	52.5	59	66.5	79	87	88	89	86	86.5
24	53	59	66.5	76	84	88	88.5	85.5	85.5
27	51.5	57	66.5	76	85	86	87	85.5	84.5
30	50	55	65	74	82	88	88	85	85
33	50	55.5	64	72	81.5	86	86	84	85
36	49.5	54	62.5	73	80	83.5	86.5	83	84

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	88	87	84	95.5	94	92	96.5	96	99.5
6	87	87	83.5	93.5	94	98	97	99	95
9	87.5	86	82.5	92.5	95.5	92.5	96	97	99
12	87	86	82	91.5	93	94.5	94.5	96	98
15	87	86	82	90.5	94	93.5	96.5	96	97
18	87.5	86	82	89.5	93	93	96	94.5	95.5
21	87	85.5	81.5	88	93	93.5	95	95.5	95
24	87	85.5	81.5	88	92	92.5	95	95	96.5
27	86	85	81	87	92	92	94	93	95.5
30	86	85	81	86.5	91	91.5	95	95	95.5
33	86.5	85	80	85.5	91.5	90.5	93.5	93	94.5
36	85.5	84.5	81	86	90	92	94	93.5	94

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	97.5	87	82	84	88.5	83	79.5	75.5	67
6	94	91.5	89	85	85	81.5	77.5	76.5	69.5
9	92.5	85	83.5	85.5	89.5	82.5	77	73	64.5
12	98	86	80.5	83.5	89	83	77	72	64.5
15	97	91	80.5	81.5	87	83	76.5	73.5	63.5
18	95.5	91.5	86	81	84	79.5	77	72	61
21	93.5	91	86	81.5	83	79	75	71	62
24	94	89.5	87	83	82	78	74.5	70.5	59
27	94	86	86	82	82.5	76.5	72	68.5	59
30	95.5	87.5	86	82	86	76.5	74	68	58.5
33	94.5	86.5	82	82	87.5	76	71	67	58
36	93.5	88	81.5	81	85.5	79	70.5	65.5	57

TABLE XVII
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 24"
Duct covering: None
Supported at: Joints
Termination: None

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	67	74	84.5	90.5	92.5	93	92	90.5	89.5
6	64.5	71	82.5	88.5	92	93	93.5	89.5	88
9	62	69	78	85.5	91	92	92	89	88
12	58	66	75	84.5	90.5	91.5	92.5	88.5	89
15	55	61.5	70.5	82	89	92.5	92	87.5	88
18	54.5	62.5	70.5	80	87.5	90.5	91	87	86
21	54	59.5	70	82.5	88	90	90.5	86.5	88
24	55	61.5	67.5	79.5	85	89.5	89	86	87.5
27	54.5	58	67.5	78	86	90	91	86.5	86
30	56	58	65.5	74.5	85.5	87	92	86.5	86
33	54	59.5	66	76.5	80.5	90	89.5	86	83.5
36	51.5	56	64	76	87	88.5	82	85	85.5

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	88	87	83.5	95	93.5	92.5	96.5	96	99.5
6	88.5	88	83.5	94	95	98	97.5	99	95.5
9	89	87.5	83	92.5	96	92.5	97	97.5	99.5
12	87.5	87	82.5	93.5	93.5	94.5	95	96.5	97.5
15	89	86.5	81.5	92.5	94	93.5	97	96	97
18	88	86.5	82.5	90.5	94	93.5	96.5	95	96
21	87.5	86.5	82	89.5	94	93.5	95.5	95.5	95
24	88	86	81.5	89.5	94	93	96	95	96.5
27	87.5	86	81	88.5	93	92.5	95.5	93.5	95.5
30	86	85.5	81.5	87.5	92.5	92.5	96	95	96
33	87	86.5	81.5	87.5	92	91.5	95	93.5	94.5
36	84.5	86	80	86.5	91	92.5	95	94	94

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	97.5	87.5	82	84.5	89	83.5	80	76.5	68.5
6	94.5	91.5	89.5	85	85	81.5	77.5	76	69.5
9	93.5	84.5	84	86	89.5	82.5	77	73.5	64.5
12	98	86.5	81	83.5	89.5	83	77	73	64
15	96	91	80.5	81.5	87	83	76.5	73	63.5
18	95.5	91.5	86.5	81	84	79.5	76.5	72	61
21	93.5	91	86.5	81	83.5	79.5	75	71.5	62
24	95	89.5	87	83.5	81.5	78.5	74.5	71	59
27	94	86	86.5	82	82.5	76.5	72.5	69	59.5
30	95.5	87.5	85.5	82	86	76.5	73.5	68.5	58.5
33	95	86.5	82.5	82	88.5	76.5	71	67.5	56.5
36	93.5	88.5	81.5	81	85.5	79.5	71	66	56

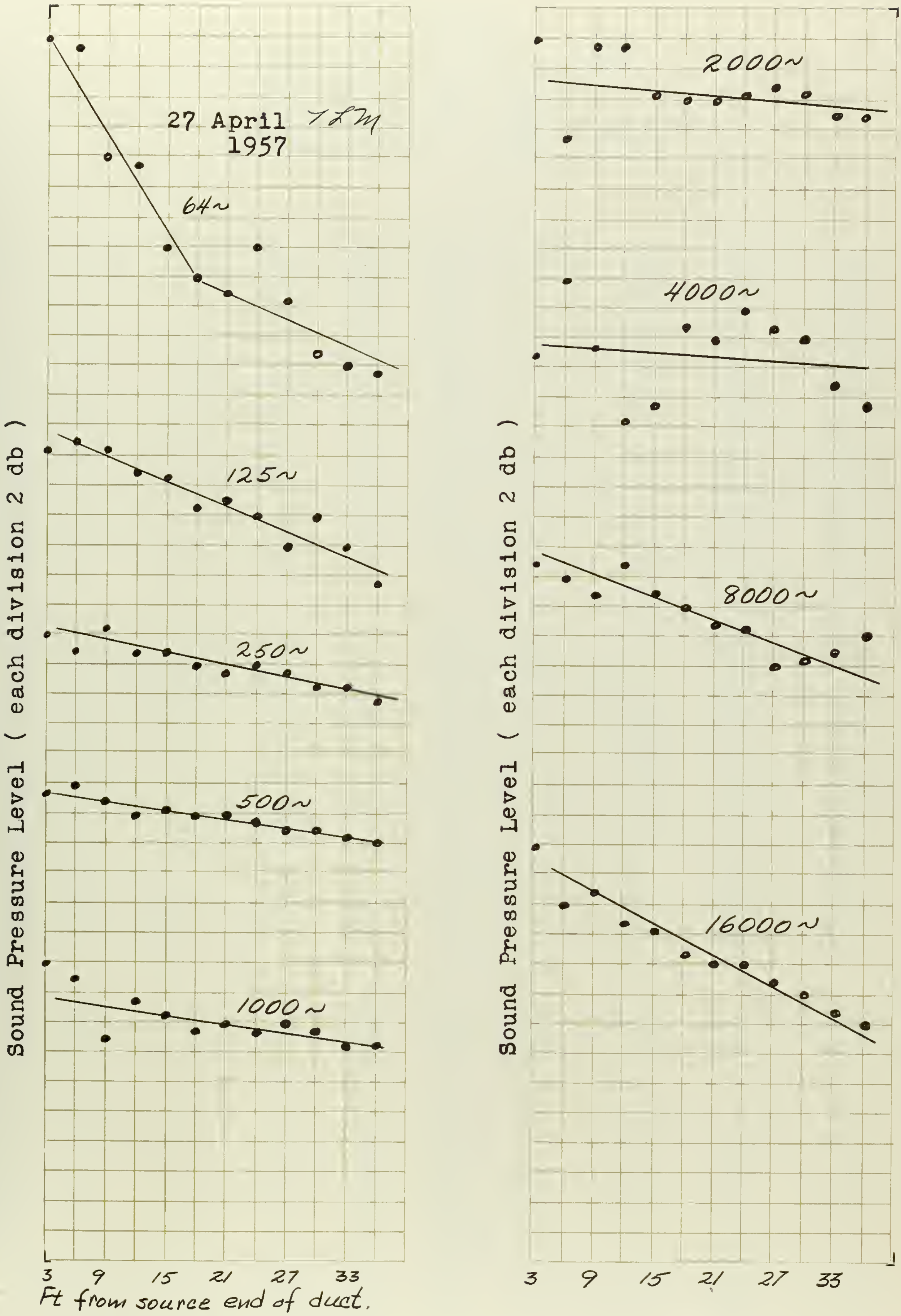

Figure XXII. Measured SPL in 12" X 24" bare duct.

TABLE XVIII
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 24"
Duct covering: Aerocor
Supported at: Center of panels
Termination: 100 wedges

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	70	78	86.5	92	94	94.5	94	92	91
6	64	74	82	91	92	95	93.5	91	90.5
9	60	67	78	89.5	93	93	92.5	90	89.5
12	56	63.5	72.5	85	90	93	92	90	89.5
15	54	60	67.5	82.5	88.5	92.5	92	89.5	88.5
18	52.5	58.5	68	81.5	87.5	90	91.5	87	88.5
21	52	58	66	80	87.5	91.5	91	86.5	87.5
24	51	57	66	76	85.5	90	89	86	88
27	49.5	54.5	62.5	75.5	85	88	89	85.5	86.5
30	49	54	64.5	74.5	83	87.5	89	85.5	85.5
33	48.5	53	61.5	72	82.5	87	86.5	84	85
36	47	51.5	60.5	72.5	79.5	84	86.5	83.5	85.5

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	90.5	89	85	97	95.5	100	101	99.5	102
6	90	88.5	86	95	96.5	99.5	100.5	102	96.5
9	90	88	84.5	94.5	97.5	94.5	100.5	100	102
12	90	89	84.5	95	95.5	98	98.5	99	101.5
15	89.5	88	84	94	96.5	96	99.5	98.5	98
18	88.5	87.5	83	92.5	95.5	95.5	99.5	98.5	98.5
21	89	87.5	83.5	91.5	96	96	96.5	98	99
24	88	87.5	83	91.5	95	94.5	96.5	97	98
27	88	87	83.5	91.5	95.5	95.5	96	96.5	98
30	87.5	87	83	91	94.5	95	96	96	98.5
33	87	87	82.5	91.5	95	94.5	96.5	97	97
36	87.5	86	82	92	94.5	95.5	96.5	96.5	98

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	101	90.5	86	87	92	86	80	79	71
6	94.5	95	92	86	87	81.5	78	76	68
9	96	89	87	89.5	92	84	80	76	67.5
12	100.5	90	82	84	92	86.5	78.5	74.5	64.5
15	99.5	94	83	82.5	87.5	84	79	72.5	64
18	98	94	89	82	86.5	82	78	72	62.5
21	96	94.5	88	82	85	81	75.5	73	62
24	95	92.5	89	84.5	83.5	80	75.5	72	61
27	97.5	88.5	88.5	84	83.5	78.5	75	70.5	60
30	98.5	89	87.5	84	86	78	73.5	69	59.5
33	96.5	89.5	84.5	84.5	89	78.5	73	68	59
36	97	92.5	83.5	84	87.5	81	73	66	57

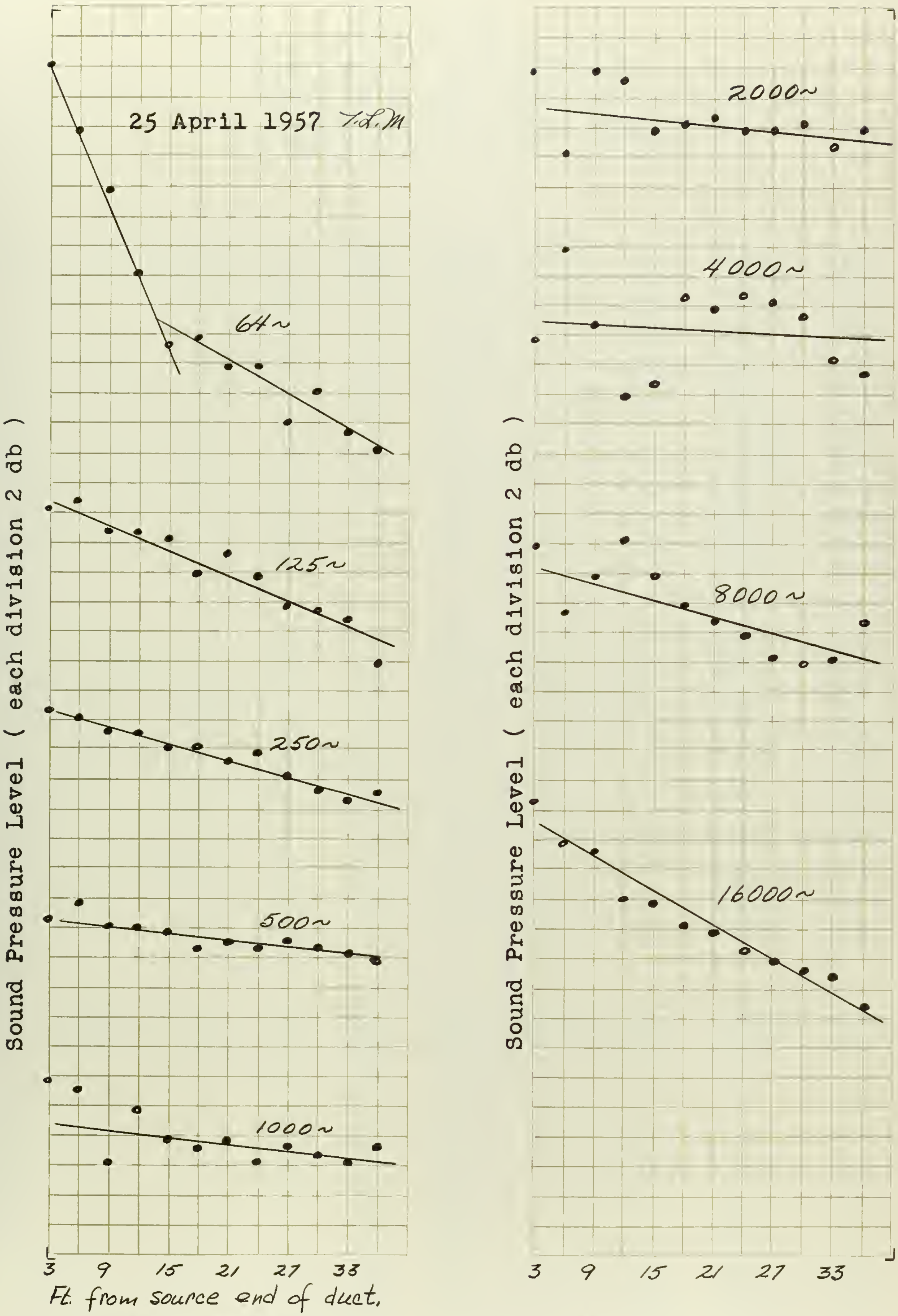

Figure XXIII. Measured SPL in 12" X 24" duct, Aerocor cover.

TABLE XIX
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 24"
Duct covering: Semi-rigid P. F. Board
Supported at: Center of panels
Termination: 100 wedges

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	74	85.5	92.5	89.5	93	93.5	92.5	91.5	90.5
6	70.5	81.5	89.5	88.5	91.5	93	92.5	89.5	89
9	64	77.5	85.5	86.5	90.5	91	89.5	89	88.5
12	63	75.5	84	84	86.5	91	90.5	88	88
15	59.5	70.5	80	82.5	85.5	89.5	90	86	86.5
18	55.5	66	75.5	80	85	88.5	88	85.5	86
21	53	64	73.5	78	85	87.5	88	85.5	85.5
24	50.5	62	70.5	74.5	80.5	86	86.5	84.5	85
27	49.5	58.5	66.5	74	78.5	85	85	82.5	84.5
30	47	53	58.5	72	76	83.5	85.5	83	83
33	47	54.5	62.5	65.5	76	82.5	84.5	80.5	82.5
36	50	61	68	64.5	71.5	80.5	83.5	80	81.5

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	89.5	89	85	96	94.5	98.5	101.5	99.5	101.5
6	89.5	88.5	85	94	96	98.5	101	101	95
9	89	87.5	84.5	93.5	97.5	94.5	100.5	99.5	100.5
12	88.5	87.5	84	93.5	95	96	97.5	98.5	99.5
15	87.5	87	83.5	93	96	95.5	97.5	97.5	97.5
18	87	86.5	83	92.5	95.5	95	97	97	98
21	87	86	82.5	91.5	95.5	95.5	95.5	97	97
24	86	85.5	82	90.5	94.5	94.5	96.5	96.5	96.5
27	85.5	85	82	90.5	95	94	95.5	95	97
30	84.5	84	81	89	95	94	97	95.5	96
33	85	84.5	80	88.5	94.5	93	95	95	96
36	84	84	80.5	89	94	93.5	95	94.5	95.5

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	100.5	90.5	84	86	91	86.5	82	76.5	70.5
6	94.5	93.5	91.5	85	88.5	82	78	75	67.5
9	94.5	87	84	88	90.5	82	80.5	75	65
12	99	89	81.5	83	91.5	85.5	78	73	64.5
15	99	93.5	82	81.5	87	83.5	78	72.5	64.5
18	97	93	88	82	85.5	80	76.5	71.5	61.5
21	95.5	93	86.5	82	84	79.5	75	74.5	61.5
24	95	91.5	88	84	84.5	79	75.5	71.5	62
27	97.5	88.5	87	83	83	77.5	75	69.5	59.5
30	97	88	86	84	86	77.5	73	68	58
33	95.5	88	84	84	87	77	72	67.5	57
36	95	90	82.5	82	85.5	79	72.5	65.5	58

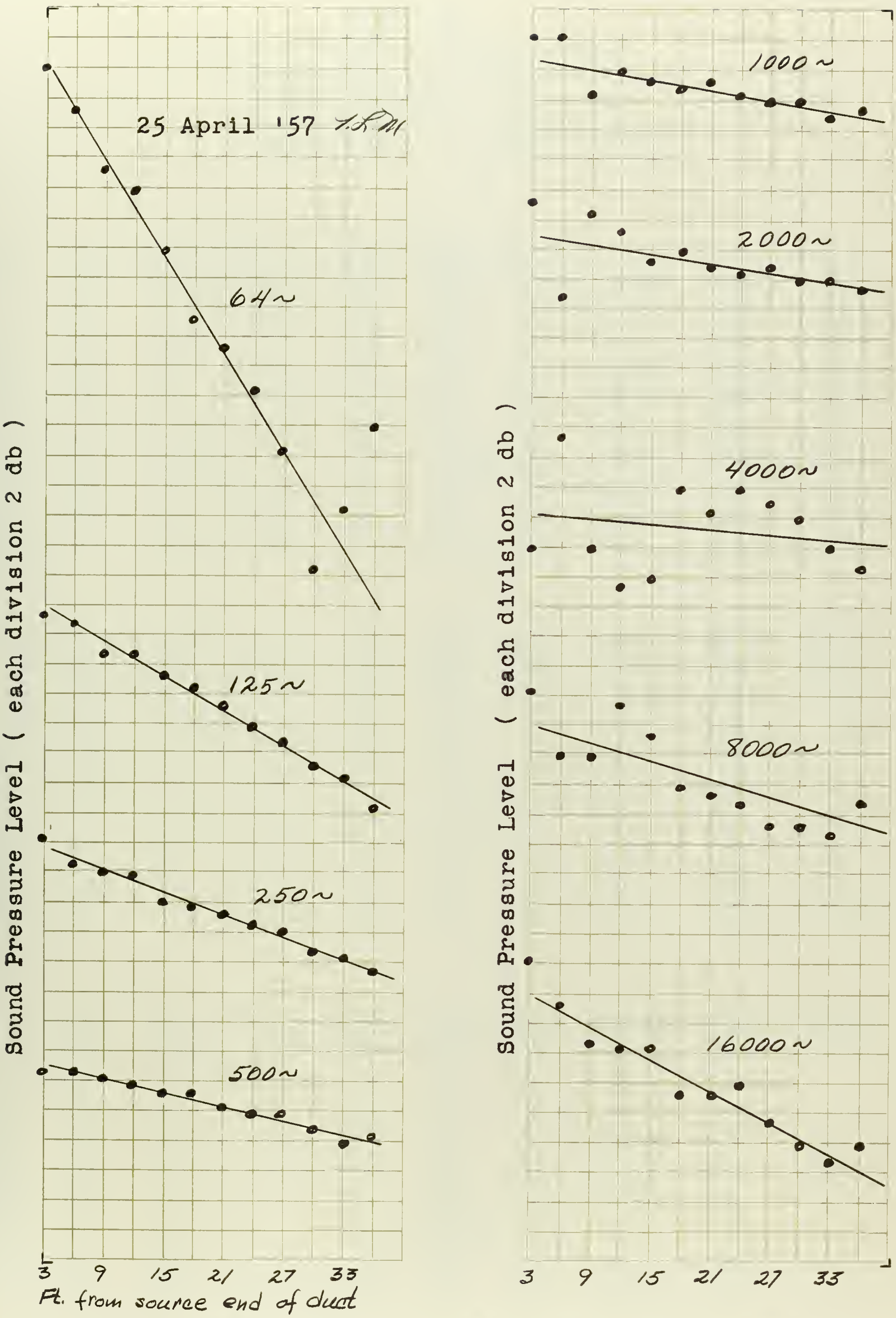

Figure XXIV. Measured SPL in 12" X 24" duct,P.F. board cover.

TABLE XX
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 24"
Duct covering: Semi-rigid P. F. Board
Supported at: Center of panels
Air flow: 1450 ft/min

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	94	89	89	91	92	92.5	92	85.5	85
6	89	85.5	87	89	90	91.5	91.5	85	84.5
9	86	83	85	87	87	90	91	84	83
12	80	80	82	84	86	88	89.5	82.5	81.5
15	80	78	78.5	82.5	84	87	89	81.5	81
18	77.5	75.5	76.5	80.5	83	85	86	80	81
21	76	76.5	75	77.5	81.5	85	85	78	79
24	74	71.5	71	76	79.5	83.5	84.5	76 5	77.5
27	74	71	70	74	79	82	84	76	76.5
30	75	72	70	73	75	79.5	83	76	76
33	74	71	70.5	71.5	76.5	80	82	75.5	76

	320	400	500	640	800	1000	1250	1600	2000
3	80	80	76	76	79	74	76	73	70
6	79.5	79.5	75.5	76	78	76	75.5	73	70
9	79	78.5	75	76	78.5	73.5	75	72.5	69.5
12	79	77.5	74.5	75.5	78	75	75	73	70
15	77.5	77.5	74	76	77.5	72.5	74	73	69
18	76.5	76	73	75	77.5	73.5	73	70.5	67.5
21	75	75.5	72.5	74	75.5	72	73	70	67
24	74.5	75	72	73.5	75.5	73	72	70	67
27	75	75	72	74	76	71.5	72	69.5	67
30	76	75	72	74	76	73.5	73	70.5	67.5
33	74	74	72.5	73.5	76	72	72	70.5	67.5

	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	67	65.5	62.5	60.5	60	59.5	58.5	57	54
6	67.5	64.5	62.5	61	60	59	58.5	57	-
9	66	64.5	63.5	62	61	60.5	58.5	57.5	-
12	66.5	65	63	61.5	61	60.5	58.5	57.5	-
15	66	64.5	63.5	62	61	60	58.5	58	54.5
18	64.5	63.5	62	60	60	59.5	56.5	55	50
21	64.5	64	63	61	60	58.5	56.5	55	49
24	64	62.5	61.5	59	58.5	57 5	55.5	54	48
27	64	62	61	58.5	58.5	56.5	55	53.5	47
30	65	62.5	61.5	60	59	57.5	54	52	46
33	64	62	61	59	58	56	52.5	51	-

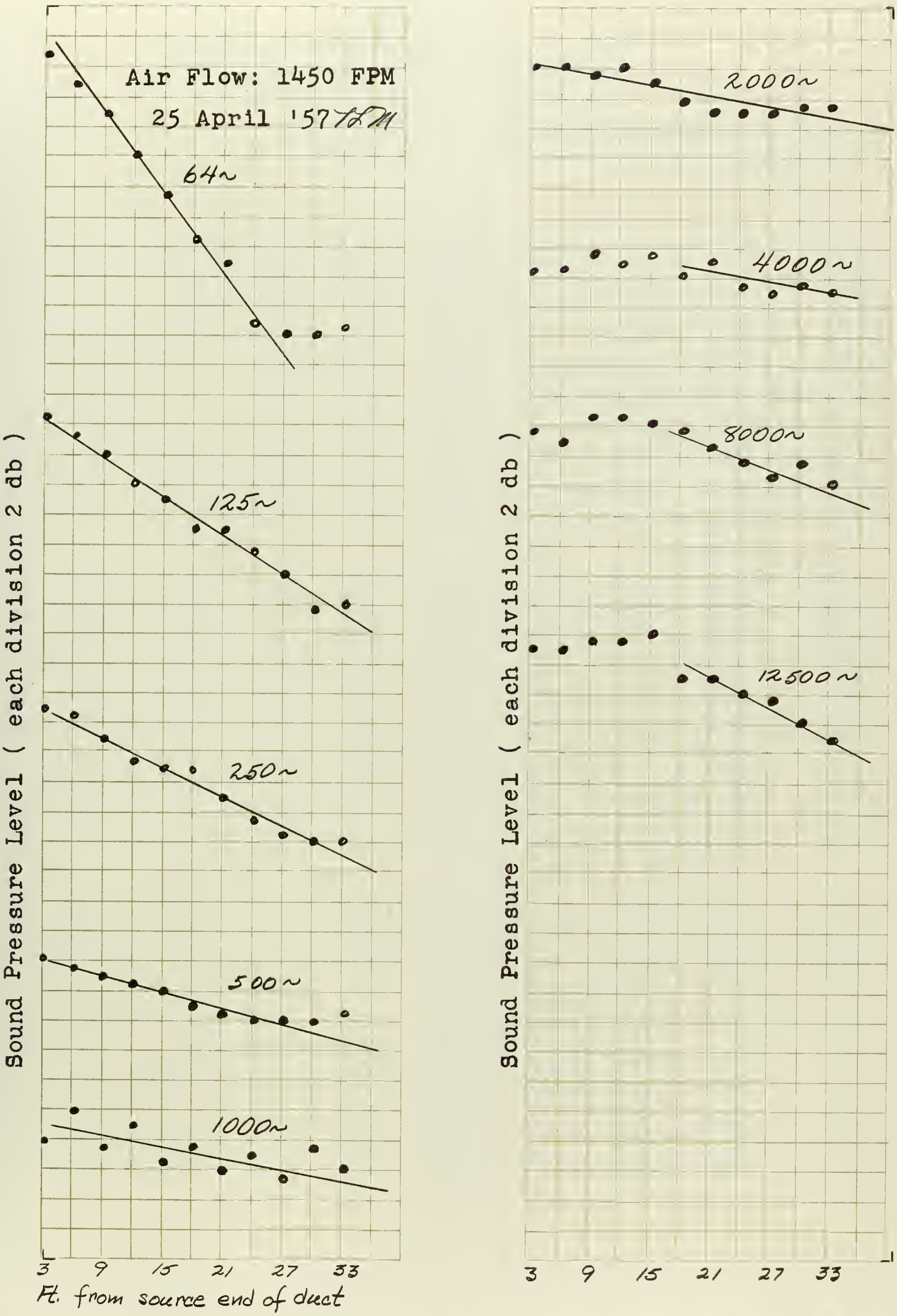

Figure XXV. Measured SPL in 12" X 24" duct with air flow.

TABLE XXI
MEASURED SOUND PRESSURE LEVELS

Duct size: 12" X 12"
Supported at: Joints
Termination: Exponential Horn
Air Flow: 1250 FPM (white noise added)

Mid-frequency of 1/3 octave bands:

Ft.	40	50	64	80	100	125	160	200	250
3	73.5	49.5	72.5	84.5	93.5	95.5	88.5	91	88.5
6	70.5	47.5	68	82	94	94	86.5	90.5	88.5
9	70.5	46	67.5	80	92.5	94	86	90	89.5
12	68	45	63.5	78	92	93.5	85	89.5	87.5
15	62.5	-	62.5	76	91	94.5	85.5	89.5	88
18	67.5	-	64	73.5	89.5	92	83.5	86	87
21	68	53	62	74.5	90.5	92	83.5	86.5	87
24	68	55	62.5	72	87.5	92	83	85	86
27	68	55.5	61.5	72.5	89	91.5	82	84	86
30	66	-	60.5	72.5	86.5	91.5	83	82.5	87.5

Ft.	320	400	500	640	800	1000	1250	1600	2000
3	86	86.5	84.5	79	86.5	87.5	88	95	98.5
6	85.5	84.5	83.5	79	87.5	88.5	87	94	98.5
9	86	86	83.5	79.5	87.5	87	87.5	94	98.5
12	85.5	84.5	82.5	78.5	87	88.5	88.5	93.5	96.5
15	86.5	84.5	82.5	78	86.5	86.5	88	92	98
18	84.5	84	82	78.5	86	87.5	86.5	91.5	96
21	85	83.5	82.5	78.5	86.5	86.5	88	92	96
24	84.5	83	81.5	78	85.5	87	88	91.5	96
27	84.5	82.5	80.5	78	86	86	88.5	91	94.5
30	83.5	82.5	81.5	77.5	85	86.5	88.5	90	95.5

Ft.	2500	3200	4000	5000	6400	8000	10000	12500	16000
3	100.5	93.5	89	86.5	90.5	87	81.5	75	67.5
6	98.5	93	88.5	86	89	85.5	80.5	73.5	64
9	99.5	92	88	85	89.5	84.5	79.5	72.5	64.5
12	98	90.5	86	84	87	82.5	77	70.5	61
15	97.5	90.5	85.5	83	88	80.5	75.5	68.5	58.5
18	97.5	89.5	85.5	82.5	85	80.5	74	67	57
21	96.5	89	85	81.5	85.5	79.5	73	65.5	56
24	96.5	89	84	81	85	79	71.5	64	55
27	95.5	88.5	82	80.5	84.5	78	70.5	62.5	54.5
30	96	88	82	79	83	77.5	70.5	61.5	54

APPENDIX D

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